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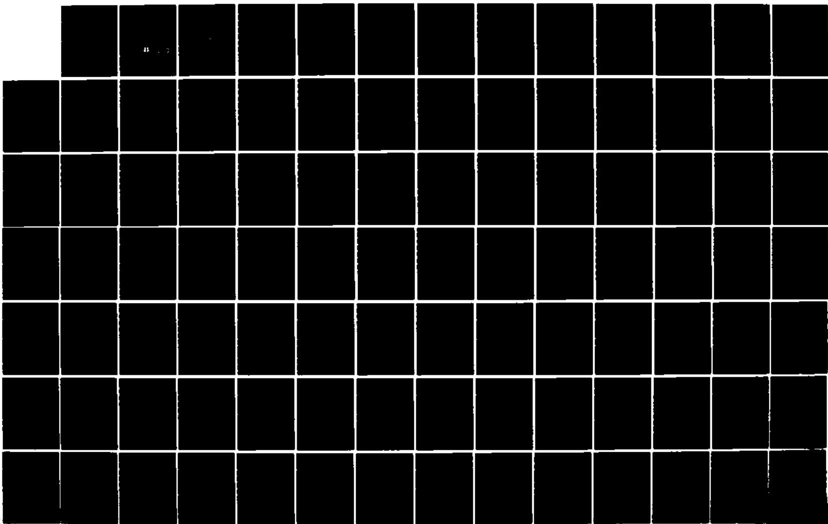

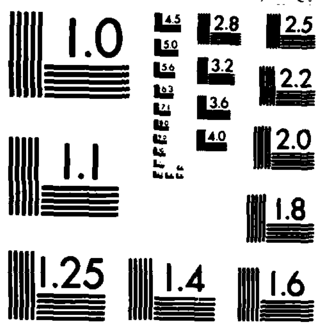

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ASSURED INFORMATION FLOW CAPPING ARCHITECTURE

By

MURRAY D. BLACK
NEIL A. CARVIN

MAY 1985

Prepared for
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REVIEW AND APPROVAL

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The Tactical Air Control System (TACS) is that set of Tactical Air Force assets used to assess the air and ground situation, and to plan, allocate, commit, and control assigned resources. Previous studies noted that the TACS elements should be more highly distributed to improve survivability in the battlefield of the future. This document reports on the results of the Assured Information Flow Capping Architecture study, which developed governing concepts for communications architectures that can support the information flow requirements of a future, distributed TACS. Architectures comprising existing and planned communications equipment were postulated and compared with a set of goals to identify deficiencies. Architectures using new equipment that resolve many of the deficiencies were then postulated, and areas needing further investigation were identified.

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EXECUTIVE SUMMARY

The battlefield of the year 2000 will include new classes of surveillance and weapon systems, with increased attrition of facilities. As a result, the communications architecture supporting the ground-based TACS will not satisfy the future system requirements if today's communications concepts continue to be used. The Assured Information Flow Capping Architecture study determined how the communications architecture can be improved to satisfy the future system requirements. The concepts developed include a highly distributed network structure, which improves the ability of the architecture to distribute information successfully, even in a high attrition environment in which numerous switches and transmission links have been destroyed.

The communications resources in the highly distributed network can be considered a utility available to the necessary subscribers. The network becomes an entity functionally separate from, but serving, the operational users. The separation is achieved by allowing the users to share the communications resources. Any message can travel to its intended destination(s) along any set of transmission links providing the requisite connectivity. Other resources, such as satellite capacity or radios for communication with mission aircraft, are not dedicated to specific C^2 facilities, but are available to all qualified users. The destruction of a satellite terminal or collocated group of ground/air radios would, therefore, not eliminate that communications capability for a nearby C^2 facility.

In order to analyze communications architectures, alternative TACS deployment configurations, representing a range of possibilities, were postulated. Goals against which the communications architectures that support these deployments can be measured were established. The survivability of communications architectures that use only existing and planned equipments were assessed relative to the goals, and significant deficiencies were noted. Alternative concepts to resolve many of the deficiencies were developed, and the required activities necessary to achieve the improvements were identified.

Three deployment configurations, each specifying an alternative physical relationship between TACS elements, were postulated. The first represents a baseline because it is similar to the current TACS deployment concept. In this configuration, each ground-based C^2 facility is deployed with a sensor and a set of radios for communications with mission aircraft. The second deployment configuration differs from the

first in that the sensors and radios are no longer paired with C^2 facilities. The third deployment configuration does not use ground-based sensors or radios other than those associated with mobile subscribers in the forward area. Airborne sensors provide forward-area surveillance coverage, and airborne relays would be required to provide forward-area coverage for communications with mission aircraft.

A future communications architecture must meet several goals to satisfy the TACS requirements. Information must be delivered in a timely manner, even in a high attrition environment. As long as at least one tandem set of links is functioning between two elements, information should be able to flow between them. The network should ideally be resistant to radio electronic combat, including jamming, exploitation, spoofing, and destruction. The establishment of communications links distributing time-sensitive information should not delay command center or sensor operations.

The communications architecture postulated using only existing and planned equipments does not meet the goals because it can be disrupted easily. The radiating elements can be detected, located, and attacked. After an attack, the remaining switches and technical control facilities have only a limited capability to respond rapidly to the loss of transmission links. The destruction of a single switch or technical control facility would result in a major loss of communications, due to the hierarchical structure of the network and the concentration of assets in a few large facilities. In addition, communications between control facilities and mission aircraft are limited to the line-of-sight regions covered by ground-based radios since no airborne relays are used. For those deployments that do not use static facilities in the forward area, the communications coverage region will be correspondingly limited.

Since the future architecture will not meet the established goals if only existing and planned transmission and switching equipments are used, other equipments must be considered. However, there is no single transmission medium that meets all of the TACS requirements. Therefore, the same types of transmission equipment that support today's TACS will continue to be used. Individual links between switches will have to be tailored for specific threats, required capacities, and operational constraints. Because the media that effectively conceal a signal from an enemy are not suitable for the long, high capacity transmission links required in the TACS, the network supporting each deployment should be designed under the realization that many radiating elements can be detected, located, and attacked by an enemy. To compensate for this vulnerability, the structure of the future network should be highly distributed. This type of network can provide assured information flow, even in a high attrition environment.

An alternative set of communications concepts was developed to support the assured information flow process. The concepts feature highly distributed switching, multiplexing, and technical control capabilities. Small switches are dispersed throughout a deployment region and are linked together in a nonhierarchical mesh network. The mesh network provides several routes for information to travel between switches, minimizing disruptions caused by the loss of one or more transmission links or switches. Each switch performs the technical control function by continually monitoring the status of the network and determining the best route for information to travel; thus, the network adapts automatically to changing connectivity.

Packet switching was found to be the switching alternative best satisfying the network connectivity goals. Packet switching algorithms that adapt the network dynamically to changing connectivity have already been developed. It has also been found to be the most efficient alternative for distributing a mix of short- and long-length, voice and data messages. Because packet switching interleaves different messages, good message delay statistics are achieved for both time-sensitive and routine information.

All information transmitted by the future TACS network will be processed by one or more packet switches. Both data and voice messages will need to be exchanged. Data message lengths will range from very short surveillance messages to very long data base updates. A message can be distributed to a single destination, to a limited number of destinations, or to all possible destinations.

Before the alternative communications concepts can be implemented, several investigations and development activities must be performed. These efforts, which are summarized below, should serve to apply the technology expected to be available in the 1990's to the TACS-unique requirements.

1. Determine, by performing the following analyses, if a highly distributed, packet-switched network to support the future TACS is actually feasible:

    a. Verify that the propagation delays expected to occur in the highly distributed network can be kept small enough to ensure that information will be delivered while it is valuable. Switch processing speeds and capacity should be based on reasonable assumptions of the technology available in the 1990's.

    b. Determine how interfaces between elements of the packet switched network and other TACS elements can be implemented.

c. Estimate the relative cost of developing and demonstrating the packet-switching hardware and software. The estimate should be relative to the cost of obtaining similar equipment for a TACS using today's communications concepts. The designs should proceed from reasonable assumptions of 1990's technology.

2. Develop protocols and procedures for the packet-switched network that efficiently and in a timely manner distribute diverse types of information to a single destination, to a small group of destinations, and to all possible destinations. The protocols should support communications between ground-based facilities and mission aircraft by allowing an authorized network subscriber to access an unassigned radio anywhere in the deployment region. The network should also deliver messages transmitted by mission aircraft to their intended destinations. Voice packets, to improve the efficiency of the network, should be transmitted only when a speaker is actually talking. The protocols should include algorithms for distributing network and subscriber connectivity information, which will be used for planning and technical control purposes.

3. Refine the concepts and perform a comparative analysis of the following three configurations for communications with mission aircraft:

   a. A purely ground-based configuration in which any authorized subscriber of the packet switched network can access any ground-to-air radio.

   b. A hybrid combination of ground-based and airborne radios in which a single ground-based packet switched network interface is provided for each operating airborne relay.

   c. A hybrid combination of ground-based and airborne radios in which an airborne relay is able to communicate with several packet switched network interface stations that are located at each ground-based C^2 facility.

In summary, architectures comprising existing and planned communications equipment were postulated and compared with a set of goals to identify deficiencies. Architectures using new equipment that resolve many of the deficiencies were then developed. Packet switching was determined to be the best technology for the future architecture. The investigations and development activities necessary to implement the alternative communications concepts were identified.

SECTION 2

INTRODUCTION

Tactical air forces are organized and equipped to operate in the environmental conditions experienced in most areas of the inhabited earth. These forces may be employed independently, in coordination with U.S. ground and naval forces, and/or in coordination with the military forces of other friendly nations. The tactical air forces may operate from pre-positioned postures overseas, or they may deploy to areas where little or no preparation for U.S. military involvement has been made. The spectrum of activities performed ranges from humanitarian airlifts through full-scale defensive and offensive air operations against enemy air and ground elements.

The Tactical Air Control System (TACS) is that set of Tactical Air Force (TAF) assets used to assess the air and ground situation, and to plan, allocate, commit, and control assigned resources. It consists of both ground-based and airborne elements. Other facilities providing support to and interfacing with the TACS include airbase navigational aids and terminal control facilities, centers for the analysis and dissemination of weather information, and facilities for gathering, analyzing and distributing intelligence information.

A study (reference 1) conducted by the Electronic Systems Division (ESD) Deputy for Development Plans and the TACS-2000 Working Group reached the following conclusions:

1. New classes of airborne sensor and weapon systems currently in development by the U.S. will bring major changes to the battlefield of the future.

2. The development of similar capabilities by the Soviet Union is highly possible.

3. As a result, the positioning of today's deployable TACS within the battle zone will be impracticle.

The study concluded that "if the deployable TACS is to be capable of operations in the most intense threat environment, it must be highly distributed." Distribution of the TACS elements does not mean that the logical command structure will change, but rather that the functions will be organized into one or more separate modules, and the modules will be dispersed.

Technology advances, when extrapolated into the future, can be expected to support this concept in terms of distributed, redundant data bases and required data processing. Most modules will be identical in terms of external optical and electromagnetic appearance, thus denying the enemy clues as to the location of the command structure. This concept is beginning to appear in recent acquisitions, for example, the Modular Control Equipment operations module replacement for the Control and Reporting Center (CRC)/Control and Reporting Post (CRP) and the Forward Air Control Post (FACP).

The Computer-Assisted Force Management System provides automation support to the Tactical Air Control Center (TACC), Air Support Operations Center (ASOC) and Wing Operations Center (WOC). For the longer term, a module identical to that used at the CRC could be postulated for use at these centers, with the only difference between modules being that of the computer software and resident data bases.

The capabilities and deployment of air surveillance sensors will change. The sensors may be ground-based and airborne, and they will be more difficult to detect and attack. The sensors will perform automatic target detection and tracking. The track information will be broadcast on an air surveillance network that, in conjunction with the sensors of other services, develops the "Recognized Air Picture." The sensors may be remoted from the C^2 modules, and will probably be more numerous. All properly equipped C^2 modules and aircraft will have access to the "Recognized Air Picture."

The advent of a near-real-time ground surveillance capability will transform today's preplanned offensive counter-air and interdiction missions into immediate missions. All properly equipped C^2 modules and aircraft with a need to know will have access to the ground situation data.

The challenge is to provide improved communication capabilities with the following attributes for the ground deployable TACS:

- Supports all information flow requirements
- Is responsive to the Commander's needs
- Is responsive to the deployment transportability and set-up time requirements
- Is survivable in the expected intense radio electronic combat environment
- Is logistically supportable

The purpose of this report is to develop governing concepts for communications architectures that can support the information flow requirements of the future, distributed TACS. An additional objective is to identify and define studies and development activities necessary to obtain the required communication capabilities. While this investigation was conducted using the contingency (ground deployable) TACS as a model, the conclusions reached are equally applicable to the theater-unique TACS.

Section 3 postulates three alternative deployment configurations and provides a gross estimate of the time-sensitive information flow rates.

Section 4 defines the goals that a future TACS communication architecture should satisfy.

Section 5 discusses key elements of several communication architectures that use equipment currently in acquisition and development, compares the architectures with the goals, and identifies deficiencies.

Section 6 identifies a new set of architecture concepts that address the deficiencies identified in the previous section and compares the new concepts with the goals.

Section 7 delineates a set of required activities that must be performed before the alternative concepts can be implemented.

Appendix A briefly describes the communications equipment that is expected to be in the TACS inventory if currently approved acquisition and development programs are carried to completion, and from which the future TACS communications architecture will evolve.

Appendix B summarizes the relative merits of three switching technologies, as well as hybrid combinations of the various approaches.

Appendix C supplies detailed information on alternative means of providing an airborne relay capability for communications between static facilities and mission aircraft.

SECTION 3

FUTURE TACS DEPLOYMENT CONFIGURATIONS AND INFORMATION FLOW

The precise physical configuration of the future ground-based TACS cannot be specified at this time, but a detailed description is not required to postulate supporting communications architectures. It is reasonable to expect that today's functional requirements will continue to exist. The functions, however, may be distributed differently. The information flow required to support the TACS will change in three ways: 1) the number of digital data messages exchanged will increase significantly; 2) more time-sensitive information requiring wide and limited distribution will be introduced; and 3) the existing air and ground surveillance information will be distributed to more C^2 facilities.

Three deployment phases are described in section 3.1. The sustained phase, one of the three, will be emphasized in the analysis of deployment configurations. A discussion of the various TACS facilities that may exist in the future is provided in section 3.2. Three candidate deployment configurations, each specifying an alternative physical relationship between the TACS elements, are postulated in section 3.3. The types of information flow that a future TACS communications architecture must support are summarized in section 3.4.

3.1 DEPLOYMENT PHASES

Reference 1 defined three phases of deployment: surge, build-up, and sustained.

a. Surge - The first Air Force actions in an emerging theater. No U.S. surface forces have been deployed. Most command and control functions are performed on airborne platforms.

b. Build-up - Additional Air Force elements and ground forces are introduced as the deployment transitions from the surge to the sustained phase. Communication links are established between ground elements to carry the minimum essential traffic. Command and control functions transition to the ground.

c. Sustained - The Tactical Air Force is fully deployed and may be engaged in joint operations with other U.S. and friendly nation forces. Wideband, switched communication links replace the point-to-point communication links established during the build-up phase. The original links may be maintained for backup use. Airborne C^2 elements continue their air and ground surveillance functions.

Additionally, in order to better survive in a nuclear environment, the operations modules may separate by distances averaging between 10 and 20 miles. Thus, the facilities would be completely dispersed, leaving no local clusters.

3.2 FUTURE TACS FACILITIES

Fixed, static, and mobile facilities are all used in today's TACS and each may be required in the future. The following definitions will apply throughout this report. Fixed facilities are not transportable. Static facilities are transportable, but they cannot communicate while moving. Mobile facilities require the capability to communicate while moving. For example, an airbase is a fixed facility, a Control and Reporting Center is a static facility, and a Tactical Air Control Party is mobile.

Command and control facilities in today's TACS are the primary locations for control and surveillance elements. C^2 facility characteristics are discussed in section 3.2.1. Different alternatives affecting the deployment of sensor facilities are presented in section 3.2.2. A similar set of alternatives for the radios that support communications with mission aircraft are considered in section 3.2.3.

3.2.1 Command and Control Facilities

We have made certain assumptions relative to the deployment of the command and control facilities in the 2000 time frame. These assumptions are discussed below.

The operations modules will be separated by several kilometers in order to minimize losses from wide area munitions. The modules will also be separated from radiating elements to reduce the probability of collateral damage resulting from physical attacks against the easily locatable radiating elements. Data bases may be distributed redundantly to increase the probability that critical functions can be performed by surviving modules, if the modules originally carrying out these functions are destroyed. Automated capabilities in these physically identical modules will be used to support the functions performed in today's Tactical Air Control Center (TACC), Control and Reporting Center (CRC), Forward Air Control Post (FACP), Air Support Operations Center (ASOC), and Wing Operations Center (WOC). Each module will contain sufficient memory and processing capacity to store and maintain the data bases required to assume other C^2 functions.

Tactical airbases are the normal locations for aircraft squadrons. Each of these bases includes a Wing Operations Center, Terminal Air Traffic Control Element, and a Tactical Airbase Weather System, in addition to other elements. The Air Force Component Headquarters, Tactical Air

Control Center and associated intelligence elements may also be located at one or more of these bases. The Airlift Control Center and Airlift Control Elements may be located at airbases with airlift squadrons. Large numbers of support personnel would typically be located at each tactical airbase. The airbase elements would often be dispersed over several square miles.

Dispersal airbases provide alternate locations for the aircraft. These airbases may be airstrips without fixed supporting facilities. Combat Control Teams may provide air traffic control services at these sites. A Wing Operations Center detachment may also operate at each dispersal airbase.

Mobile command and control facilities consist primarily of Tactical Air Control Parties and Combat Control Teams. They may be moving while they perform their functions.

3.2.2 Sensor Facilities

Sensor facilities are the primary locations for active and passive, ground-based surveillance systems. Significant changes are expected to occur in regard to air surveillance and control. The Recognized Air Picture will be distributed to all C^2 facilities needing the information. The acquisition and distribution of this information may be accomplished in a number of ways. Today's air surveillance and control concept may be retained, with each ground-based C^2 facility equipped with a dedicated air surveillance sensor. Alternatively, the sensors may be deployed independently of the C^2 facilities, such that the sensors and C^2 facilities are not paired. In this configuration, the sensors would perform the automatic track initiation, tracking and target classification functions. A third alternative would replace the forward-area, ground-based sensors with airborne sensors to enhance survivability.

Disassociating the C^2 facilities from the sensors would result in a significant increase in operational flexibility yet impose new requirements on the supporting communications network. For example, the CRC (or its designated successor in case of destruction) would assign a region of responsibility to each subordinate FACP that could be independent of the FACP's physical location. This geographic area could be varied to adapt to changing regional target loads and to attrition of C^2 facilities.

Current development activities in the area of ground surveillance and control will result in a significant improvement in acquiring and maintaining the ground situation picture and in the reaction time for offensive counter air and interdiction missions. The Precision Location

Strike System (PLSS) will provide the capability to locate and identify emitters, provide threat warning, and guide munitions to the emitter location. JOINT STARS will provide the capability to detect, track and direct weapons against second echelon ground targets. The Ground Attack Control Center (GACC) will provide the capability to track and direct weapons against second echelon ground targets, using inputs from separate sensor systems and through integrating the capabilities of PLSS and JOINT STARS. The Recognized Land Picture will be distributed throughout the theater of operations and be available to all C^2 facilities needing the information.

3.2.3 Radios for Communications with Mission Aircraft

Various radio equipments are required to support communications between ground-based elements and mission aircraft. Each C^2 facility in today's TACS is deployed with a complement of radios dedicated to the facility. The dedicated radios concept could be retained, or an alternative configuration could be used. The deployment alternatives for these radios are similar to the options discussed for the sensors in the preceeding section of this report.

One alternative would be to use radios that are not dedicated to specific C^2 facilities. The radios in this alternative would be a shared resource available to all C^2 facilities needing to communicate with mission aircraft. This alternative would allow a mission controller to communicate with aircraft located anywhere in the deployment region. The destruction of a particular group of radios would not block communications between a C^2 facility and aircraft.

Another alternative would be to remove the ground-based radios (other than those associated with mobile subscribers) from the vulnerable forward area. An airborne relay, or some other communications capability, would be required to provide forward area communications coverage. This deployment would be used if ground-based sensors were also not used in the forward area. It would remove all static radiating elements from the forward area.

3.3 DEPLOYMENT CONFIGURATIONS

Three candidate future TACS deployment configurations, representing a range of possibilities, have been postulated. Each specifies an alternative physical relationship between TACS elements. Communications architectures that serve these alternative deployments will be examined in later sections of this report.

The first deployment configuration represents a baseline because it is identical to the current TACS deployment concept. Ground-based C^2

facilities are used throughout the deployment region, with mobile C^2 facilities primarily located in the most forward areas. Each sensor is assigned to and deployed with a C^2 facility or tactical airbase. A sensor may be physically separate from its assigned C^2 facility or airbase. Radios for communication with mission aircraft are also deployed with the C^2 facilities that need this capability. The baseline deployment configuration is illustrated in figure 3-1.

The static C^2 facilities are removed from the forward area in the second deployment configuration. The sensors are used throughout the deployment region and remain ground-based. Radios for communication with mission aircraft also continue to be used throughout the deployment region. Relative to the baseline configuration, this deployment configuration is more survivable because the C^2 facilities are easier to protect. The principal deficiency of this configuration is that radiating elements remain in the vulnerable forward area. The second deployment configuration is depicted in figure 3-2.

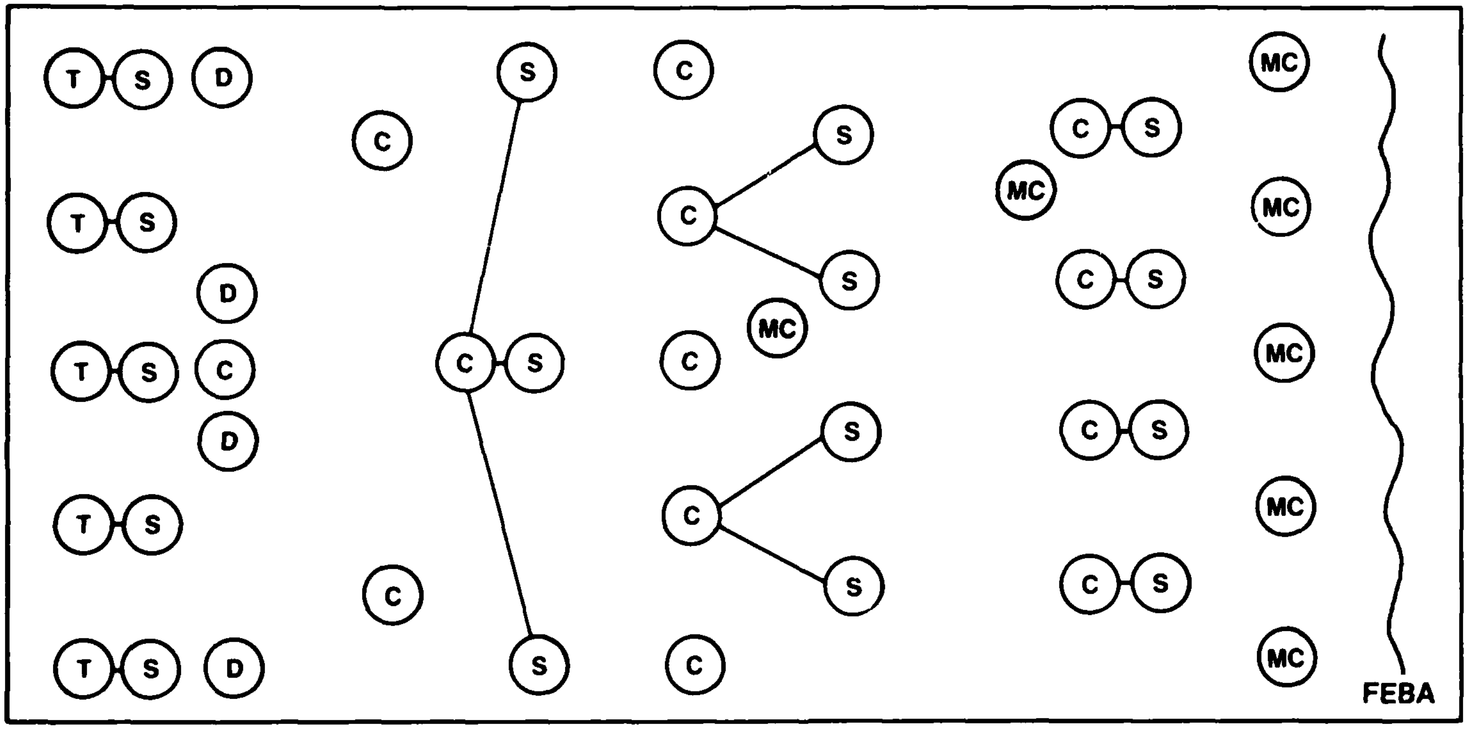
With the exception of the mobile elements (such as Tactical Air Control Parties), all radiating elements are removed from the forward area in the third deployment configuration. Air surveillance coverage in the forward area is provided by airborne sensors. Ground-based radios for communications with mission aircraft are also not used in the forward area. Communications coverage in the forward area for this requirement would have to be provided by some other communications capability, possibly an airborne relay. This deployment configuration is inherently more survivable than the two others since static radiating elements are not used in the vulnerable forward area. The third deployment configuration is shown in figure 3-3.

3.4 INFORMATION FLOW REQUIREMENTS

The TACS information flow can be categorized in terms of time sensitivity and connectivity. The amount of information flowing is largely a function of the force size deployed and the activity level.

3.4.1 Force Size and Activity Level

A fully deployed TACS has the capability to support 24 tactical fighter squadrons, 2 composite reconnaissance squadrons, 2 air refueling squadrons, and 8 tactical airlift squadrons. Fighter and reconnaissance squadrons are assumed to be equipped with 18 aircraft each, of which approximately 80% will be airborne simultaneously during the peak hour. Refuelling and airlift squadrons are assumed to be equipped with 16 aircraft each, of which approximately 50% will be airborne simultaneously during the peak hour. From these assumptions, one can calculate a total of approximately 460 sorties per peak hour.



C = C^2 FACILITY
D = DISPERSAL AIRBASE

MC = MOBILE C^2
S = SENSOR
T = TACTICAL AIRBASE

Figure 3-1. Baseline TACS Deployment Configuration

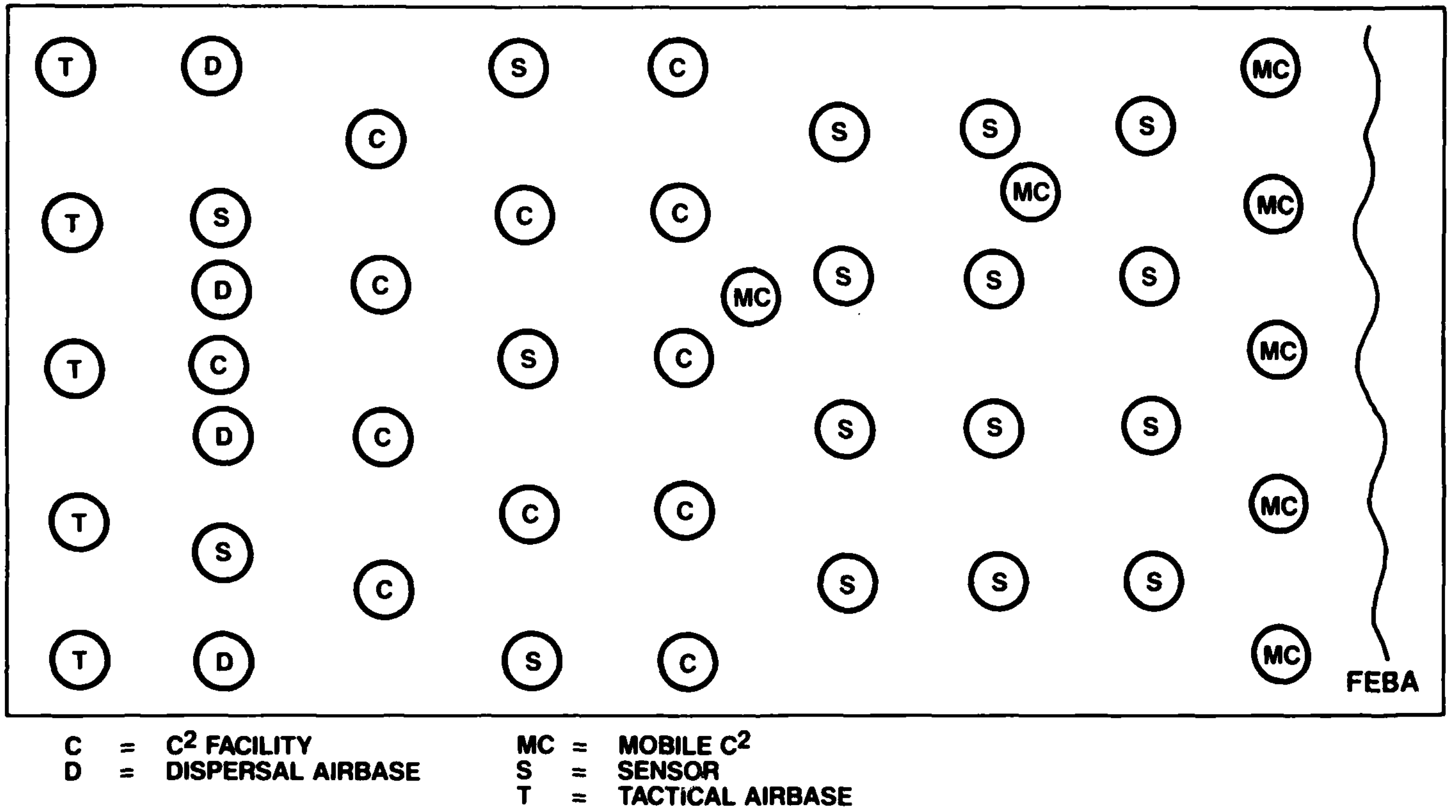
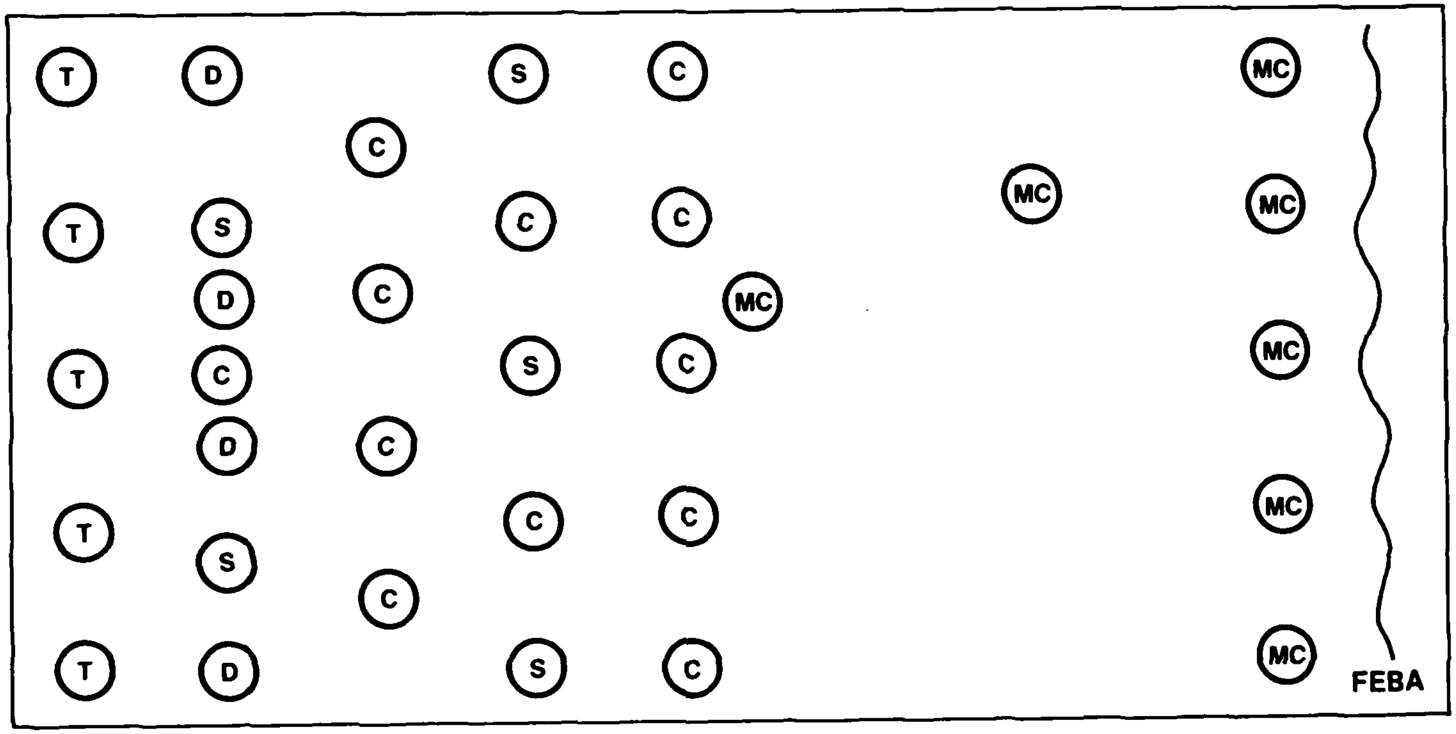


Figure 3-2. Ground-Based Air Surveillance Deployment Configuration



C = C^2 FACILITY
D = DISPERSAL AIRBASE
MC = MOBILE C^2
S = SENSOR
T = TACTICAL AIRBASE

Figure 3-3. Ground-Based & Airborne Air Surveillance Deployment Configuration

A total of 1000 aircraft are assumed to be within the reportable air-space. This assumption is consistent with that used for JTIDS network capacity studies. The scenario considered employs a single TACS in joint operations.

A total of 10,000 ground target entities, including 1,000 emitters, is assumed to be observable within the reportable ground surveillance area.

3.4.2 Information Flow

Information in the TACS is exchanged between subscribers at widely separated fixed and static locations, between subscribers at a single location, between static and mobile subscribers, and between ground-based and airborne subscribers, and between mobile subscribers.

3.4.2.1 Wide Area Communications. Wide area communications support the flow of information between operating locations separated by distances up to 200 miles. A study (reference 2) performed in 1970 for a post-1975, automated, distributed TAÇS estimated that total digital traffic density (adjusted for 32 kbps digitized voice circuits) would be approximately 5 Mbps. This rate does not include exchange of imagery information, bulk transfers of data between computers, or ground-air-ground traffic. Potential data rate reductions resulting from use of lower bit rate voice digitizers have also not been considered.

The bulk of this traffic flows between airbases and between the TACC and other C^2 elements. Time-sensitive information, defined as that information for which delays of more than a few seconds could prove disruptive, is expected to make up only a small percentage of the total information flow. There are three principal categories of wide-area, time-sensitive information: air surveillance, ground surveillance, and command and control. Each category is discussed below and a summary is provided.

3.4.2.1.1 Air Surveillance Information. Air surveillance information includes track messages generated by ground-based and airborne air surveillance sensors and track managment and identification messages generated by the C^2 facilities. This information must be accessible to all members of the tactical C^2 community needing it and to selected mission aircraft. The estimated air track message generation rate is based on a total of 1,000 aircraft operating in the reportable airspace and a 10-second average update rate. Between 100 and 200 air surveillance messages per second will be generated, each averaging approximately 200 information bits. The range in the estimate is due primarily to various estimates of the quantity of track management messages. Airborne sensors would contribute more than 50 percent of the total.

3.4.2.1.2 Ground Surveillance Information. Ground surveillance information includes ground target messages generated by ground-based facilities. The information flow estimates do not include the links between airborne sensors and their associated ground-based facilities. The GACC will be the primary source of ground surveillance information, developed using data provided by PLSS and JOINT STARS. This information must be accessible to selected mission aircraft, other GACCs, the TACC, ASOCs, TACPs, and Airborne Forward Air Controllers (AFACs). The ground target message generation rate is based on 1500 target groups in the first and second echelons, and an update rate of one minute per target group. Approximately 25 messages per second will be generated, each averaging approximately 200 bits.

3.4.2.1.3 Command and Coordination Information. Command and coordination information includes resource status, mission and target assignments, and reporting of mission results. The information can be generated by both ground-based and airborne C^2 centers and must be accessible to nearly all components of the TACS. The rate of message generation is based on a total of 460 sorties per hour for the busy hour, of which 360 sorties per hour are involved in combat actions. Approximately 7 messages per second will be exchanged among various C^2 modules and Surface-to-Air Missile (SAM) sites.

3.4.2.1.4 Time-Sensitive Information Summary. Based on the estimates provided in the three previous paragraphs, the total wide-area, time-sensitive information flow is estimated to be between 150 and 250 messages per second. The messages should average approximately 200 bits each. Depending on the deployment configuration, the wide area communications network may also be required to support information flow between C^2 facilities and radios for communications with mission aircraft.

3.4.2.2 Local Area Communications. Local area communications supports the flow of information between subscribers in close proximity to each other (up to several miles). The number of subscribers can range from a few to more than one thousand. Local area communications systems are usually sized so that all subscriber terminals can be used simultaneously. At tactical airbases, digital information flowing among air traffic control elements averages 4 messages per second. The local area communications equipment also provides access to the wide area communications network.

3.4.2.3 Communications with Mobile Subscribers. Information exchanged between static facilities and mobile subscribers is primarily between Air Support Operations Centers (ASOCs) and TACPs, and between Air Lift Control Elements (ALCEs) and Combat Control Teams (CCTs).

Approximately one message per second is contributed by the air request network, which links TACPs, AFACs, and the ASOC. These messages would average approximately 200 information bits.

3.4.2.4 Communications with Mission Aircraft. Aircraft control and reporting information is exchanged between C^2 centers (ground-based and airborne) and mission aircraft. Each JTIDS equipped aircraft will transmit a position/status/acknowledgment message every six seconds. These messages will be received by all JTIDS-equipped C^2 facilities (including terminal air traffic control facilities) within line of sight of the aircraft. In addition, the C^2 elements will transmit approximately six commands/acknowledgments per second to mission aircraft. A total of approximately 80 messages per second will be transmitted.

The amount of voice traffic flowing between static facilities and mission aircraft in the terminal areas is expected to be significant, with an average of 30-40 voice channels in use simultaneously, distributed among the ground control, terminal area control, and ground controlled approach functions.

Voice communications between C^2 facilities, such as CRCs, and aircraft are expected to be reduced significantly from today's usage due to the advent of JTIDS. Although only two voice channels, on average, are expected to be in use simultaneously, the total number of mission control channels required is 40, if today's concept of allocation is used, i.e., every controller uses a dedicated channel. (The number of controllers is estimated by assuming that a typical TACS includes one 4-module CRC, six 2-module FACPs, and two 2-module GACCs. Each module contains four consoles. Approximately 50 percent of the available consoles would be used for aircraft control.)

3.4.2.5 Summary of Information Flow Requirements. It is not possible to estimate the total information flow with certainty. The estimates discussed herein should only be used as guides. The previously mentioned study (reference 2) that led to the 5 Mbps total wide-area information flow estimate was performed in 1970 and did not attempt to assess the impact of new technology, such as the modularization or dispersion of C^2 facilities.

A key conclusion that can be reached is that the total information flow traffic density will continue to increase. Although it is impossible to quantify, the traffic density of a TACS in the year 2000 can be assumed to be several multiples of today's rate, perhaps on the order of 20 Mbps. Many types of information will need to be distributed to multiple locations.

SECTION 4

ARCHITECTURE GOALS

The communications architecture must support the highly distributed future TACS with its increased numbers of sensors and operating locations. Continuity of time-critical information is a prime consideration. The primary architecture goals of connectivity, radio electronic combat, and deployment are defined in the following paragraphs.

4.1 CONNECTIVITY

The communications network must deliver information successfully, even in a high attrition environment in which numerous switches and transmission links have been destroyed. As long as at least one set of links is functioning between two elements, information should be able to flow between them. The network should distribute the diverse types of information while using the scarce transmission resources efficiently. Information should be delivered in a timely manner, allowing it to be used while it is valuable.

4.2 RADIO ELECTRONIC COMBAT

The communications system should be resistant to radio electronic combat including jamming, exploitation, spoofing and destruction. The strategy of the adversary will be to detect and locate emitters, exploit the emission signatures to establish the communications network connectivity, and either jam critical links or destroy key nodes. The architecture should satisfy the following objectives.

a. Detection and location - the links comprising the ground-based network should be difficult to detect, and the communications equipment should be difficult to locate. The adversary can be expected to use both direction finding and time difference of arrival techniques.

b. Exploitation - the combined electromagnetic signatures of the emitters at each location should conceal the function, importance, and activity level of the locations.

c. Communications Security - all transmissions must employ communications and transmission security techniques to deny information to the adversary and to prevent spoofing.

d. Jamming - links comprising the ground-based network should be difficult to jam. The adversary should be forced into using relatively stationary airborne resources in a one-on-one configuration, thereby making them easy to locate and attack.

e. Destruction - the adversary should be forced to use highly sophisticated munitions to attack emitters. The emanations of the emitters should be difficult to detect by these munitions. The system architecture should disperse the emitters to minimize the probability of multiple emitter destruction or collateral operations module destruction by a single munition. Additionally, protection should be provided for electromagnetic pulse, and chemical, biological, and radiation weapons, where applicable.

4.3 DEPLOYMENT

The deployment characteristics of the communications equipment should be compatible with the deployment of the TACS C^2 and sensor elements.

a. Transportability - The communications equipment, including power sources, should not significantly increase the transport requirements of the element supported. This is particularly important during the build-up phase and, at all times, for mobile subscribers and forward area sensors.

   The communications equipment supporting mobile subscribers must be transported by the same vehicle as the operational personnel. Individual units must be man portable.

b. Set-up Time - The establishment of communications links distributing time-sensitive information should not delay command center or sensor operations.

   The communications equipment supporting Tactical Air Control Parties (TACPs) must operate while in motion, communicating with the ASOC, other TACPs, and mission aircraft.

   The sensor has a goal of 15 minutes from arrival on site to the beginning of operations. Communication links to all adjacent nodes should be operational within this same time period.

   The set-up goal for the first operational module of a CRC, FACP, or ASOC is 30 minutes. However, the links to the forward area sensors should be in service within 15 minutes of arrival of a sensor at a new location.

SECTION 5

COMMUNICATIONS ARCHITECTURES USING EXISTING AND PLANNED EQUIPMENT

This section postulates communication architectures that use the transmission and switching equipment that currently exists in inventory, is currently being acquired, or is in development. A brief description of the various equipments in this baseline is provided in appendix A. Each postulated architecture is assessed in terms of its ability to satisfy the architecture goals listed in section 4 and various deficiencies are identified.

Three communications architectures that use the existing and planned equipment have been postulated and evaluated. The first, described in section 5.1, is a baseline configuration because it is appropriate for deployments similar to today's TACS. The second architecture, considered in section 5.2, is appropriate for deployments in which the static C^2 facilities are removed from the forward area. The third alternative, examined in section 5.3, is appropriate for deployments in which no static facilities are used in the forward area. Airborne air surveillance sensors would be used to provide forward-area surveillance coverage.

5.1 BASELINE DEPLOYMENT COMMUNICATIONS ARCHITECTURE

The baseline deployment communications architecture discussed below serves a TACS deployed using the baseline configuration described in section 3.3 and illustrated in figure 3-1.

5.1.1 Description

The baseline architecture, illustrated in figure 5-1, includes the following features:

a. Ground-to-ground wideband links provide connectivity between all static TACS operating locations and between TACS and external locations. These links use AN/TRC-170 troposcatter radios and either the AN/TSC-94A or the AN/TSC-100A satellite terminals.

b. Ground-to-ground, HF/SSB, narrowband links provide backup to the wideband links and are also used during the build-up deployment phase.

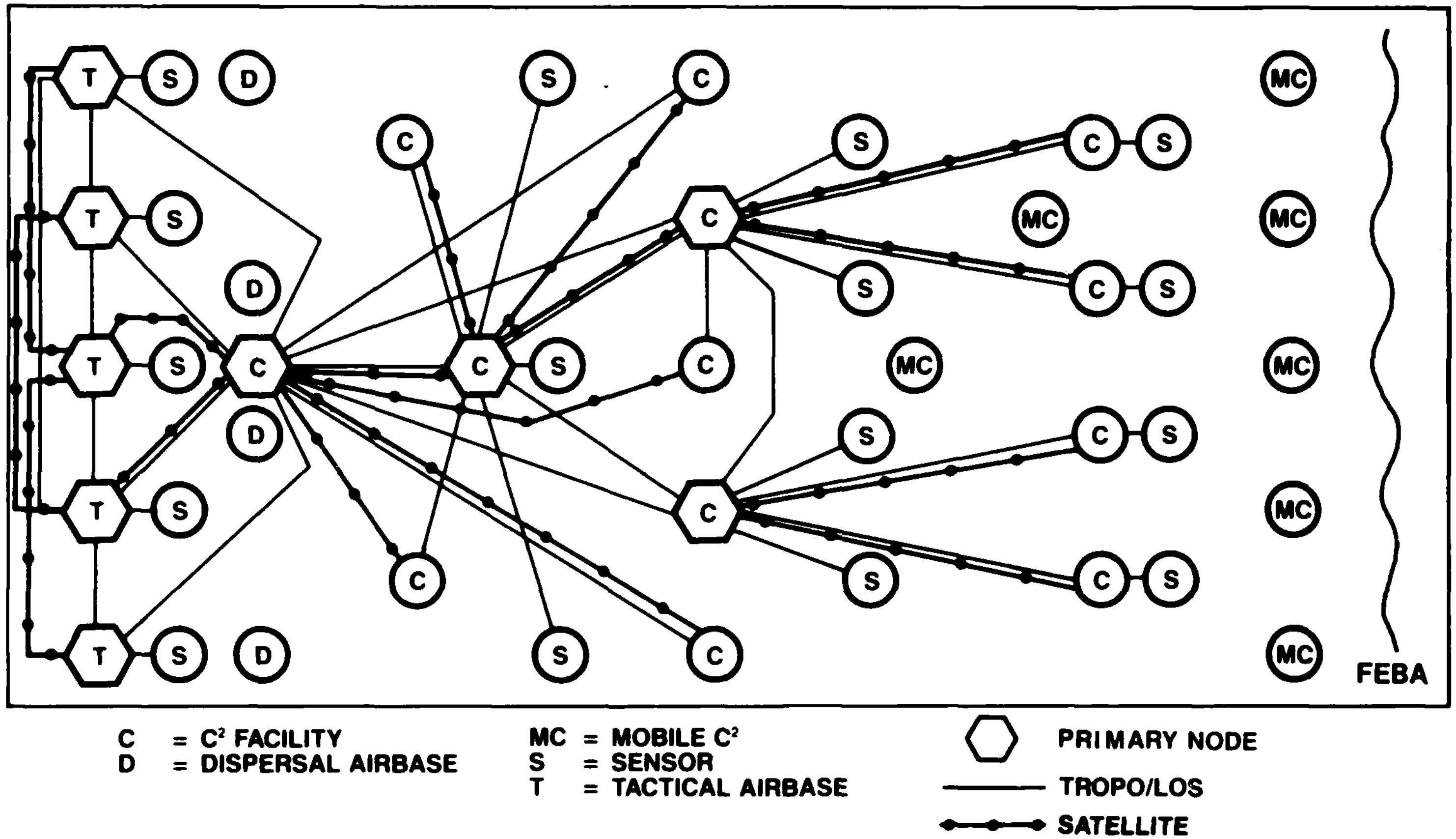


Figure 5-1. Baseline Deployment Communications Architecture

c. Circuit and message switches at primary nodes accommodate both local and wide area traffic. These switches are interconnected primarily by the wideband network.

d. Single-channel, ground-to-ground links support communications between mobile elements and between mobile elements and static elements. These links use HF radio and/or MILSTAR.

e. Links between ground elements and aircraft are providea by conventional UHF/AM, VHF/AM, VHF/FM and HF radios, and by JTIDS, Enhanced JTIDS or HAVE QUICK, and SINCGARS-V.

f. Technical control equipment at major nodes provide flexibility in interconnecting the various wide-area transmission links.

g. Local distribution at all fixed nodes is accomplished by either metallic or fiber-optic cables.

During the build-up phase of the baseline deployment, mission aircraft, sensors and C^2 facilities will be the first elements introduced. The C^2 facilities will be deployed with their organic communications assets. Each C^2 facility will be provided with a JTIDS terminal for the exchange of surveillance information and for the transmission of commands to mission aircraft. In addition, each C^2 facility will be provided with a MILSTAR terminal for coordination with other facilities. The MILSTAR SCOTT terminals will be used at ASOCs and TACPs to support the Immediate Air Request Network. The control elements use their organic ground/air radios to support voice communications with mission aircraft. All radiating equipment will be remoted from the operations modules by either fiber-optic cable or Short Range Wideband Radio (SRWBR) links.

As the deployment continues, troposcatter radios, SRWBRs, and SHF multichannel satellite terminals, together with technical control facilities and switches, will be deployed to form a highly redundant network as illustrated in figure 5-1. The switches linking the operating locations also provide local and inter-element circuit and message switching capabilities for local subscribers. Inter-element switching for remote subscribers at locations not having tandem switching capabilities is also provided.

Voice and routine message traffic will be routed through this switched network. The information distributed via JTIDS will also be relayed over the wideband links. Each operating location will transmit the time-sensitive digital information for which it is responsible over a dedicated multi-drop circuit routed to every other location requiring access to this information. Conversely, every operating location requiring access to this time-sensitive information will receive data over separate circuits, one for every element in the deployment transmitting the required information.

Mobile communication facilities and two generic types of communication nodes will provide the required switching and transmission capabilities:

a. Mobile Communications Facility - This facility supports mobile elements, such as the TACPs and CCTs. It consists of a small vehicle equipped to communicate with static elements, other mobile ground elements, and with aircraft. The projected AN/GRC-206 radio set, incorporating Enhanced JTIDS or HAVE QUICK and SINCGARS-V, will provide multi-mode voice communications capabilities. A MILSTAR SCOTT satellite terminal will provide a data communications capability. A fiber optic system will permit the radios to be separated from the operations personnel by up to 1000 meters.

b. Secondary Communications Node - This node, which is illustrated in figure 5-2, is associated with locations containing a small operations center, such as an FACP or an ASOC, and few support personnel. One or more AN/TRC-170 troposcatter radios and the AN/TSC-94 single link satellite terminal provide the principal means for point-to-point communications. HF/SSB radios and MILSTAR SCOTT satellite terminals provide back-up to these links. The radios would be located at parks several kilometers from the operations modules and be connected to the operations location via cable or Short Range Wideband Radio. The node has a limited capability to route circuits among locations by use of TRI-TAC digital group multiplex and patching equipment. Communications with aircraft is effected by the ground/air equipment at the radio parks. Local circuit distribution to operations modules will be via either metallic or fiber optic cable.

c. Primary Communications Node - This node, which is illustrated in figure 5-3, is associated with locations containing numerous operations modules, such as a CRC, and at tactical airbases. Many AN/TRC-170 troposcatter radios and one or more AN/TSC-100 multiple-link satellite terminals provide the principal means for point-to-point communications. HF/SSB radios and MILSTAR SCOTT satellite terminals are used to back-up these links. The AN/TSC-60 HF/SSB radios and AN/TSC-100 satellite terminals also provide circuits to DCS entry stations. These radios would be located at parks several kilometers away from the operations modules and would be connected to the operations location via cable or Short Range Wideband Radio. This node has the greatest capability to reroute circuits among locations and includes facilities for the switching of voice and data circuits. The AN/TTC-39 circuit switch and either an AN/TYC-39 or an AN/TYC-11 message switch support both remote and local voice and data

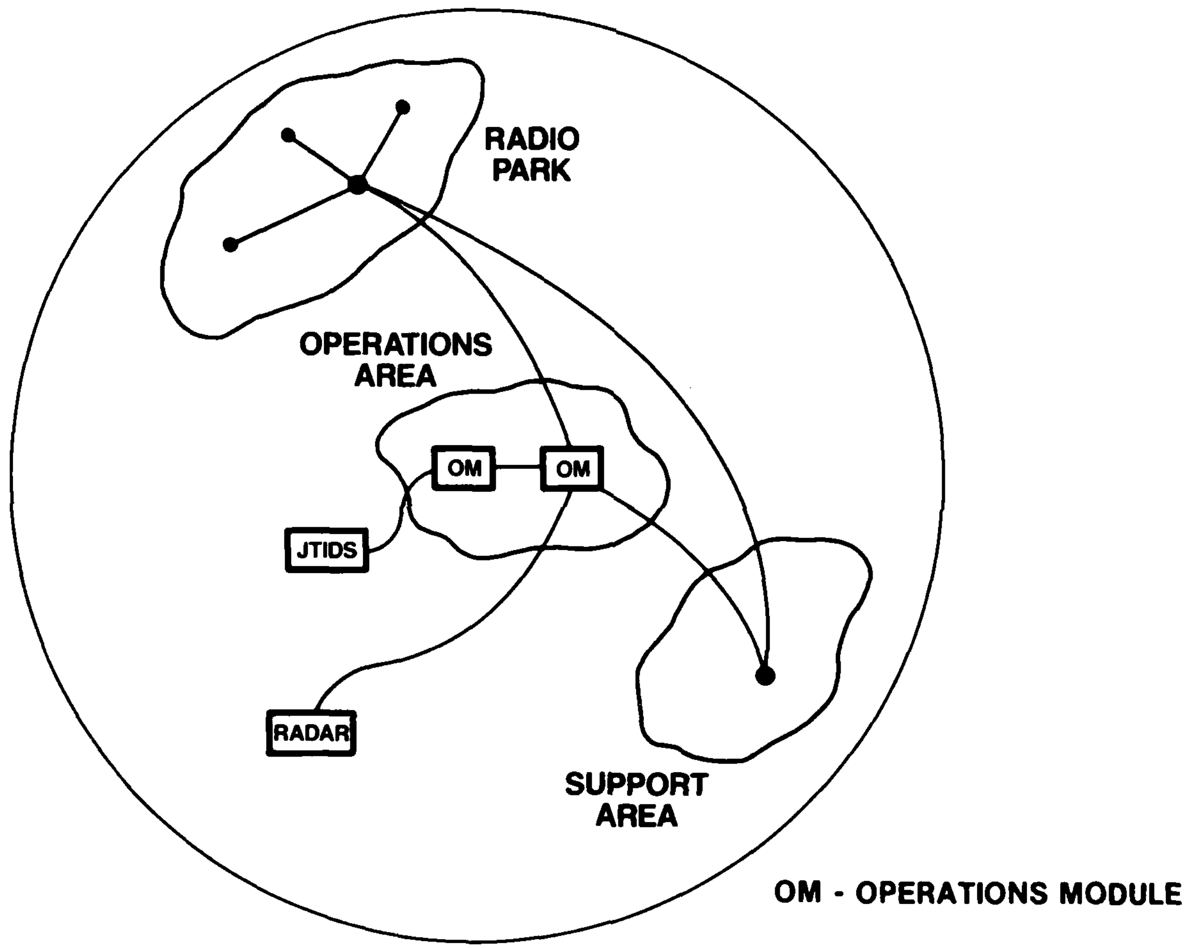


Figure 5-2. Secondary Node

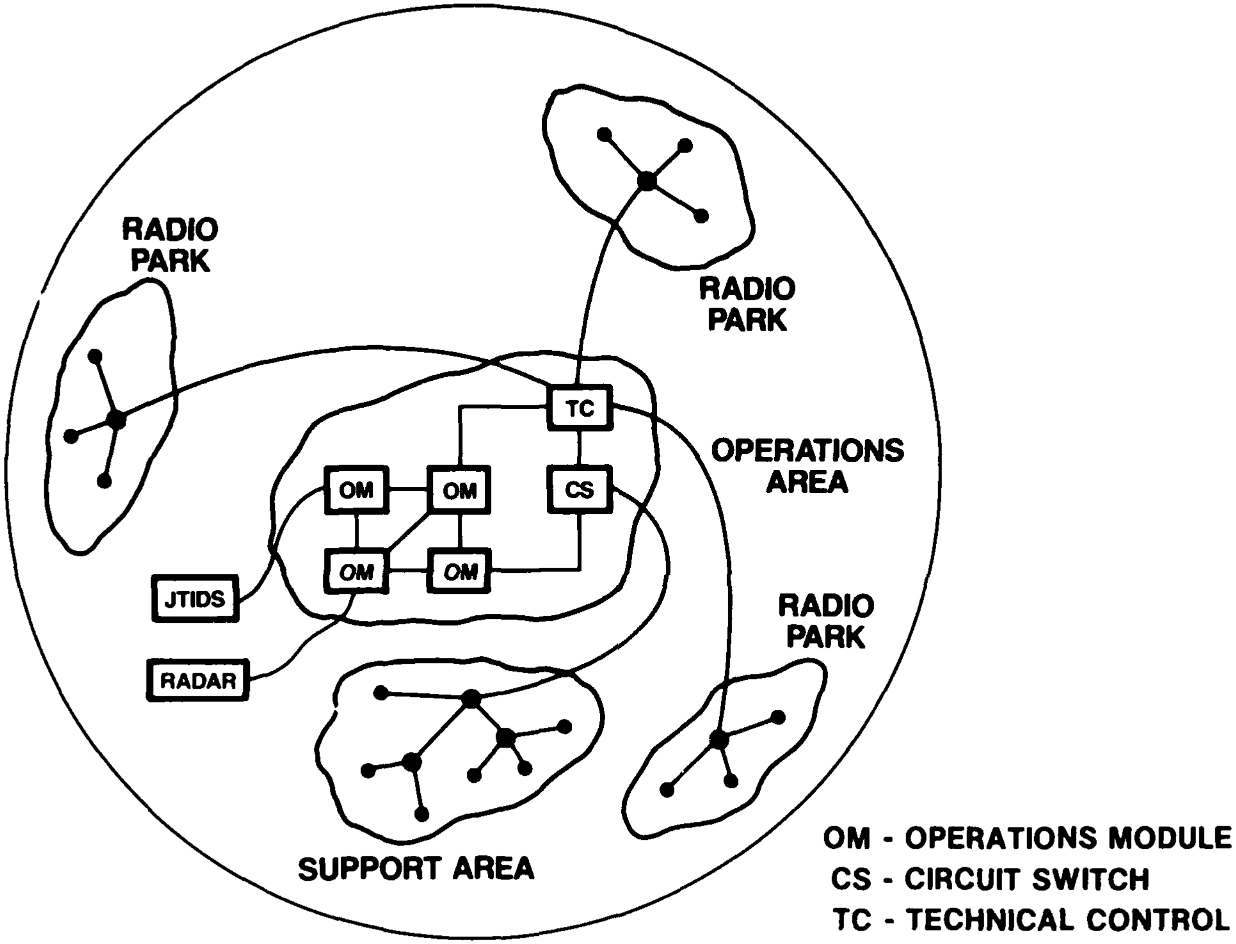


Figure 5-3. Primary Node

subscribers. Communications with aircraft is effected by the ground/air equipment at the radio parks. The Communications Nodal Control Element (CNCE) provides the interface between the local area communications network and the radio parks. Local circuit distribution to operations modules will be via either metallic or fiber optic cable.

5.1.2 Assessment

An assessment of the baseline deployment communications architecture revealed the following deficiencies. None of the existing and planned transmission equipments completely satisfy the TACS communication requirements during the various phases and types of deployments. Only fiber optic cable, troposcatter radio, Short Range Wideband Radio (SRWBR), and the DSCS satellite system can provide the high capacity required for planning and support communications. Of these equipments, only the DSCS satellite system is capable of providing communications between any two locations independent of the characteristics of the intervening geographic area and the disposition of friendly and hostile forces in that area. The troposcatter radio, SRWBR, and DSCS systems are all susceptible to detection, jamming and destruction. An attack on multiple links can disrupt the troposcatter/SRWBR network. The DSCS system can be severely degraded (less than or equal to 32 kbps per link) by jamming the satellite uplink.

Only JTIDS has the deployment flexibility, resistance to jamming, and capacity to support the distribution of time-sensitive C^2 and surveillance information. Only JTIDS, HF/SSB and MILSTAR can operate while in motion, and can therefore support mobile subscriber communications. Of these, only JTIDS and MILSTAR are resistant to jamming.

In the forward area, all of the various over-the-air radio equipments are susceptible to detection and location. At distances in excess of 100 km, MILSTAR transmissions are not readily detected. Once detected, any radio is a candidate for destruction.

In summary:

- Most links will be vulnerable to detection and disruption.
- The initial build-up deployment phase must rely on satellite and JTIDS relays for the distribution of time-sensitive information.
- The baseline TACS communication system will continue to use all of the available transmission methods.

In addition, the communications architecture described above has the following problems with regard to information distribution:

1. Only a small number of switches are employed. The destruction of a single switch will disrupt information flow at that location, disrupt most information flow to other locations, and reduce information flow between remote locations.

2. Most inter-element circuits are routed via the Communications Nodal Control Element (CNCE) at primary nodes. Destruction of this facility will disrupt the information flow to other locations and access to the ground/air radios.

3. The switches are not designed to accommodate the expected significant increase in digital information flow.

4. Network configuration planning and reconfiguration is a time consuming process.

5. Many of the operating locations do not have tandem switches. Tandem transmission is effected by cabling from one radio set to another. As a result, routing reconfiguration is slow.

6. The distribution of the Recognized Air/Land Picture will use a large number of dedicated lines, significantly reducing the network capacity available for other purposes.

7. Since each C^2 facility is supported by its own organic communication equipment, the electromagnetic signature of the equipment provides a good indicator of the function of the nearby C^2 facility.

5.2 GROUND-BASED AIR SURVEILLANCE COMMUNICATIONS ARCHITECTURE

The communications architecture discussed below serves a TACS deployed using the ground-based air surveillance deployment configuration described in section 3.3 and illustrated in figure 3-2. This deployment, like the baseline, uses only ground-based sensors to provide air surveillance coverage. However, the control facilities and their associated sensors may be widely separated. This detachment allows the removal of the static control facilities from the vulnerable forward area of a deployment region. The sensors remain in the forward area.

5.2.1 Description

The communications architecture supporting this deployment will be similar to the one supporting the baseline deployment. The principal difference is that troposcatter radios will be used to provide wideband transmission between C^2 facilities and their associated sensors and ground/air radios in the forward area. This configuration is illustrated in figure 5-4.

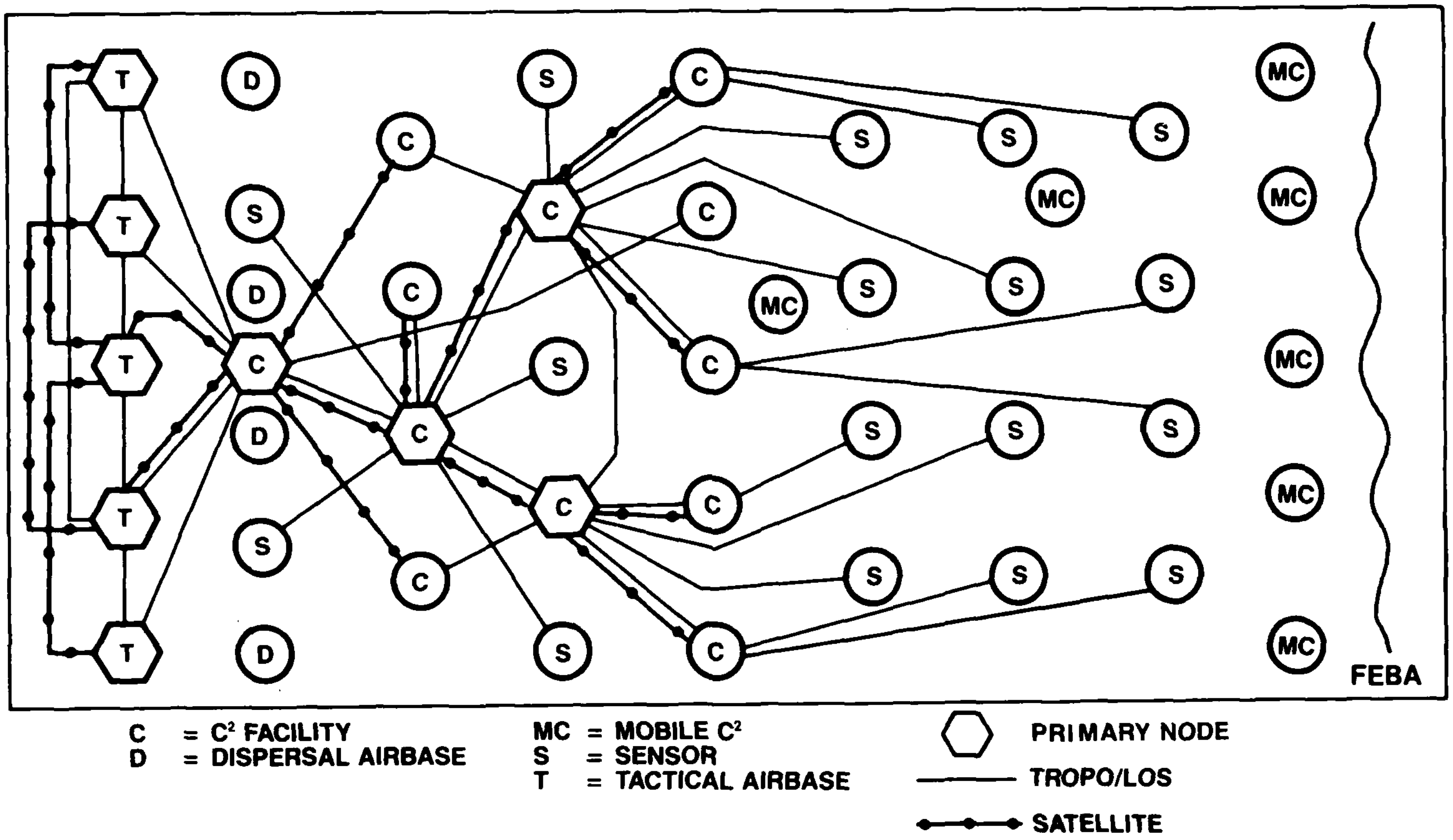


Figure 5-4. Ground-Based Air Surveillance Communications Architecture

5.2.2 Assessment

An assessment of the ground-based air surveillance communications architecture revealed the following deficiencies:

1. All of the problems identified for the baseline deployment communications architecture.

2. During the build-up phase, access to ground/air voice communications in the forward area will be delayed until the terrestrial network is established.

5.3 GROUND-BASED AND AIRBORNE AIR SURVEILLANCE COMMUNICATIONS ARCHITECTURE

The communications architecture discussed below serves a TACS deployed using the ground-based and airborne air surveillance deployment configuration described in section 3.3 and illustrated in figure 3-3. This deployment uses both ground-based and airborne sensors to provide air surveillance coverage. Ground-based sensors are not used in the forward area.

5.3.1 Description

The communications architecture supporting this deployment will be similar to the one supporting the ground-based air surveillance deployment for both the build-up and sustained phases, except in the forward area. This configuration is illustrated in figure 5-5.

5.3.2 Assessment

An assessment of the ground-based and airborne communications architecture revealed the following deficiencies:

1. All of the problems identified for the baseline deployment communications architectures.

2. Communications between static facilities and mission aircraft is limited to the line-of-sight regions covered by the rear-area radios.

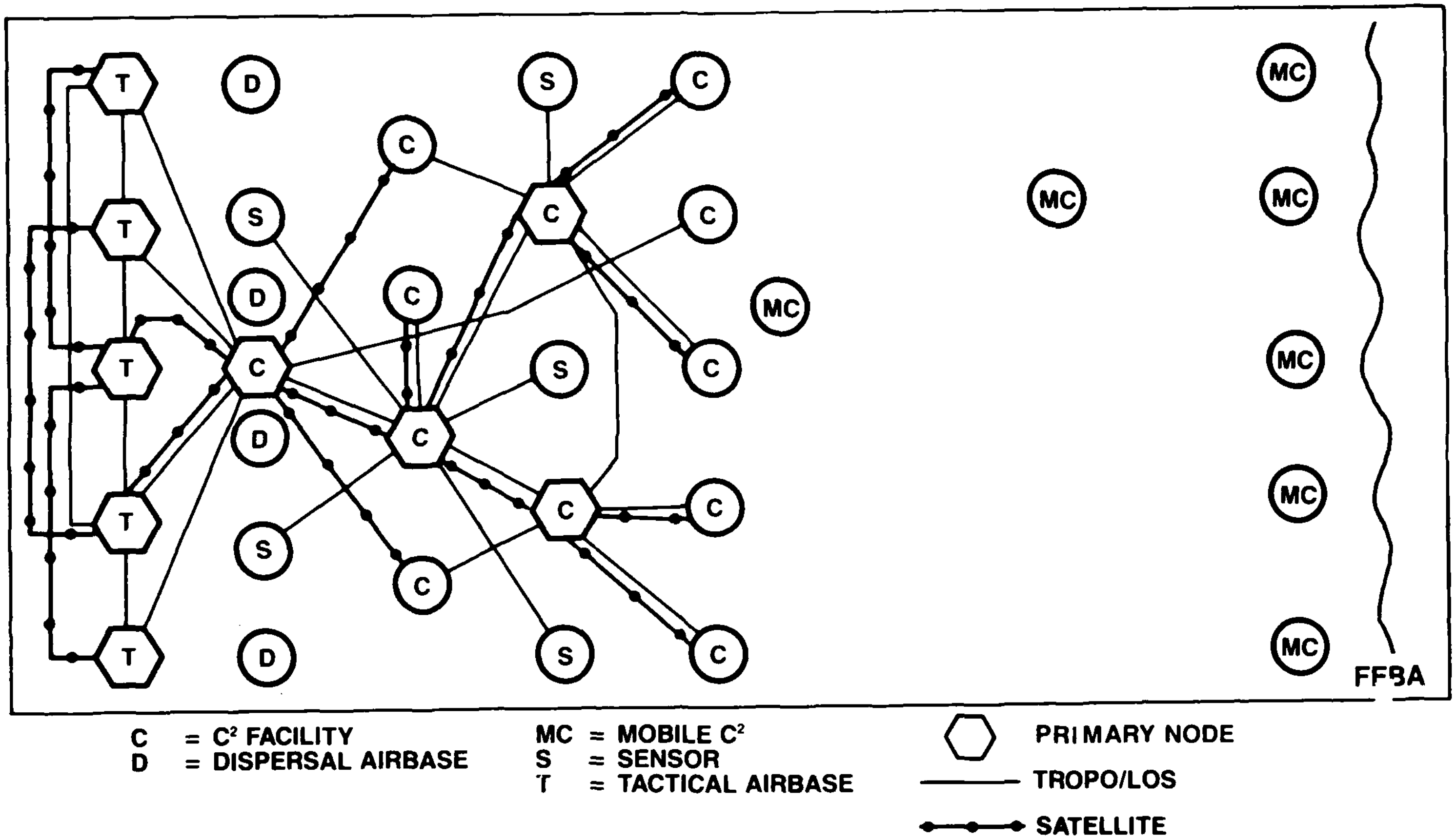


Figure 5-5. Ground-Based & Airborne Air Surveillance Communications Architecture

SECTION 6

ALTERNATIVE CONCEPTS FOR A FUTURE COMMUNICATIONS ARCHITECTURE

TACS communications architectures that use existing and planned equipment were postulated in section 5. These architectures were compared with the goals listed in section 4 and various deficiencies were identified. In this section, an alternative set of architecture concepts is described. The concepts, which apply to a range of possible future deployments, resolve many of the deficiencies characteristic of the architectures using only existing and planned equipment.

The concepts feature highly distributed switching, multiplexing, and technical control capabilities. Small switches are dispersed throughout a TACS deployment region and are linked together in a nonhierarchical mesh network. The mesh network provides several routes for information to travel between switches, minimizing disruptions caused by the loss of one or more transmission links or switches. The switches monitor network status continually and adapt the network automatically to changing connectivity.

The communications resources in the highly distributed network can be considered a utility available to the necessary subscribers. The network becomes an entity functionally separate from, but serving, the operational users. The separation is achieved by allowing the users to share the communications resources. Any message can travel to its intended destination(s) along any set of transmission links providing the requisite connectivity. Other resources, such as satellite capacity or radios for communication with mission aircraft, are not dedicated to specific C^2 facilities, but are available to all qualified users. The destruction of a satellite terminal or collocated group of ground/air radios would therefore not eliminate that communications capability for a nearby C^2 facility.

A distributed structure for a terrestrial network is postulated in section 6.1. Concepts to govern the information flow process are provided in section 6.2. An assessment of the alternative concepts is included in section 6.3.

6.1 NETWORK STRUCTURE

Information in today's TACS is transported by a communications network that is primarily terrestrial, but also uses satellite relays. The network of the future could maintain this structure, or airborne relays could be added to provide additional connectivity. However, neither airborne nor satellite relays should form the foundation of the future architecture for the following reasons: 1) the destruction of a relay would greatly disrupt information flow, possibly resulting in a major loss of communications; 2) keeping airborne relays operational is expensive and may not be possible under all weather conditions; and 3) high-capacity satellite links are vulnerable to jamming. Therefore, the future TACS architecture should remain primarily terrestrial, provided that the communications deficiencies characteristic of today's TACS can be resolved or ameliorated. Airborne or satellite relays could be used in certain applications, such as when it is not feasible or desirable to establish a complete ground network.

A comparison of the transmission media available to support a future TACS ground network is provided in section 6.1.1. A network structure that disperses the switching and technical control functions is postulated in section 6.1.2.

6.1.1 Transmission Media

The transmission media available to support a future TACS ground network include metallic and fiber-optic cable, radio waves propagated by line-of-sight and over-the-horizon techniques, and laser-generated light waves. Signals transmitted via cable, especially fiber-optic cable, are extremely difficult if not impossible for an enemy at a distance to intercept. However, cable systems are inflexible, slow to install over long distances, and require physical control of the intervening terrain. These considerations make cable unattractive for long-distance communications. Radio waves are often better media for long transmission links. In general, the information capacity (bandwidth) of a radio signal increases with frequency, but more serious propagation problems are also encountered. The excessive free-space and atmospheric attenuation at extremely high, millimeter-wave frequencies make these frequencies appropriate only for very short or low capacity links.

The ease with which an enemy can detect a signal depends on the radiated power level, the directivity of the antenna, and the magnitude of path losses. Troposcatter propagation, which can often achieve the path lengths required in a typical TACS deployment region, is easy to detect because high transmitter output power is generally used. A lower power, line-of-sight microwave link is somewhat more difficult to detect, but path lengths are limited to about 50 km in a tactical environment.

Millimeter wave transmissions are extremely difficult for an enemy to detect because of the high level of signal attenuation. Laser systems, like millimeter waves, are limited by propagation problems to less than 10 km path lengths and are also very difficult for an enemy to detect.

The main conclusion presented in this brief discussion is that there is no single transmission medium that meets all of the TACS requirements. Individual links have to be tailored for specific threats, required capacities, and operational constraints. The media that effectively conceal a signal from an enemy are not suitable for long transmisson links. The tandem combination of several short-length, concealable links instead of a single long, detectable link does not appear to be feasible due to operational and cost considerations. Therefore, the network should be designed and deployed with the realization that many TACS radiating elements can be detected and located by an enemy. The network should therefore be able to function in a high attrition environment in which numerous facilities have been destroyed. A survivable network structure using numerous switches and transmission links is described in the next section of this report.

6.1.2 Distributed Switched Network

The few, large circuit and message switches in today's TACS are configured in a hierarchical, tree structure. The detectability of the radiating elements and the paucity of switches result in a network that is vulnerable to disruption. The destruction of a switch would result in a major loss of network communications. The destruction of a technical control facility would essentially isolate the associated users from the rest of the network.

In order to resolve these survivability deficiencies, it is postulated that the network serving the future TACS will disperse the switching function. Many small switches should be linked in a nonhierarchical structure that provides numerous routes for information to travel. The technical control function should also be dispersed to allow each switch to respond independently to changing connectivity. Figure 6-1 depicts a generic form of such a network. Note that two or more transmission paths connect each switch (SW) to other nearby switches. Any switch can communicate with any other switch. There are normally several routes for information to travel between each pair of switches. Subscriber equipment, represented on the figure by the smaller circles, interfaces with the network at selected switches. Protocols define the links between subscribers and switches and the links between switches. Each switch performs the technical control function by monitoring the status of the network and determining the best route for each message to travel. To facilitate network planning activities, information describing the current network connectivity and link use is available at all locations.

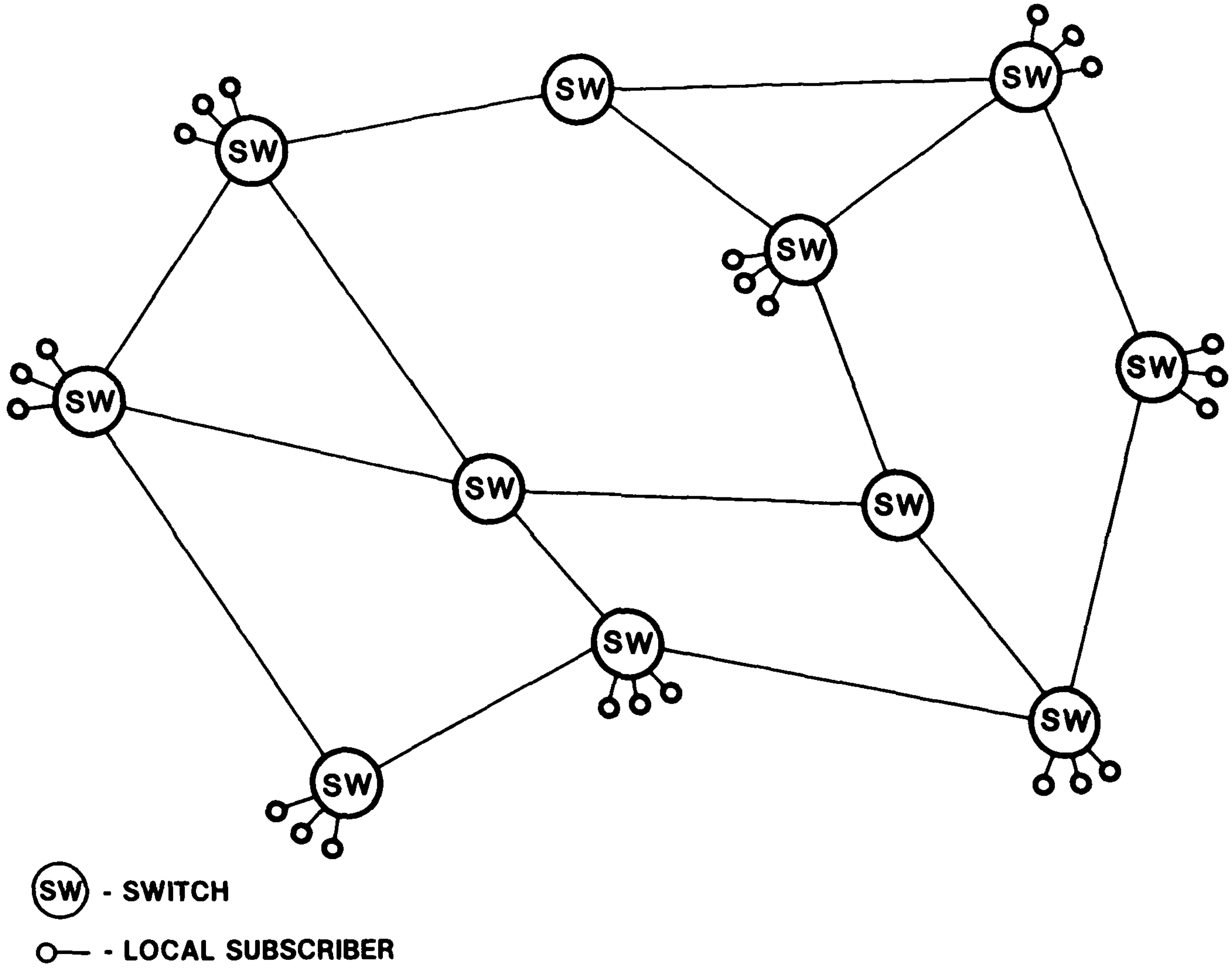


Figure 6-1. Distributed Network Structure

6.2 INFORMATION DISTRIBUTION

Various transmission media available to support a future TACS architecture were identified in section 6.1, and the structure of a distributed network comprising these resources was postulated. In this section, concepts to govern the flow of information between TACS elements are presented. The rationale for choosing a packet-switching alternative for the future architecture is delineated in section 6.2.1. A hybrid switch to accomplish the subscriber-to-switch interface, as well as to perform the standard packet switching functions, is postulated in section 6.2.2. The information flow requirements for each type of TACS element and the concepts for integrating each element type into the architecture are provided in section 6.2.3. The information flow process is described in section 6.2.4.

6.2.1 The Need for Packet Switching

The TACS communications network must relay routine and time-sensitive, voice and data information. As discussed in section 5, circuit and message switches are deployed at primary nodes in today's TACS to accomodate the necessary traffic. Dedicated point-to-point circuits are also used in the existing architecture to facilitate the exchange of surveillance information.

The future architecture must satisfy three connectivity goals to resolve the information distribution deficiencies characteristic of today's TACS. The communications network should deliver information successfully, even in a high attrition environment in which numerous switches and transmission links have been destroyed. As long as at least one set of links is functioning between two elements, information should be able to flow between them. The second connectivity goal is that the network should distribute the diverse types of information while using the scarce transmission resources efficiently. The third goal is that information should be delivered in a timely manner, allowing it to be used while it is valuable.

Three different switching alternatives were compared to find a technique that satisfies the connectivity goals. A network of dedicated circuits was the first alternative considered. Dedicated circuits provide transmission capacity that is reserved for information flow between two or more specific locations, even if there is no information to transmit. A circuit/message switching system hybrid was the second alternative considered. In today's TACS, circuit switching is used for voice and some data communications, and message switching is used for data messages less sensitive to propagation delays. Packet switching, the third alternative considered, partitions messages into short packets and then relays each packet, possibly independently, to its intended destination.

The dedicated circuits alternative is least able to satisfy the assured-connectivity goal because these circuits cannot be rerouted automatically in response to changing connectivity. Limited automatic adaptation capabilities have been developed for circuit and message switching systems, but packet switching is better suited for algorithms that adapt the network dynamically to changing connectivity. Therefore, packet switching is the alternative that best satisfies the assured-connectivity goal.

The dedicated circuits alternative is also least able to satisfy the transmission efficiency goal because capacity is wasted when no information is being exchanged. Circuit switching is an efficient means for distributing long messages, but the transmission overhead associated with circuit switching's call set-up procedure is excessive for short messages. Packet switching appears to be the most efficient alternative for distributing a mix of short- and long-length, voice and data messages (references 3,4,5,6 and 7).

Message switching is the alternative least able to satisfy the timeliness goal. A long message can monopolize network resources in a message switching system, which could delay the transmission of time-sensitive messages for a period greatly exceeding their useful lifetime. Packet switching can interleave different messages, which improves message delay statistics for both time-sensitive and routine information. Dedicated circuits, when designed properly, can deliver information with the least delay.

It is clear, based upon this evaluation, that packet switching is the alternative best satisfying the three connectivity goals.

6.2.2 Hybrid Switches

One problem that will be encountered when packet switches are introduced into the TACS is that the existing subscriber switching and terminal equipment is not directly compatible with packet switching. It is neither operationally feasible nor cost-effective to achieve packet switching compatibility immediately. Therefore, to accomplish the switching functions during a transition period, the development of a hybrid switch has been postulated. This switch would receive information from and deliver information to subscribers via circuit, message, and packet-switching techniques. The specific switching technique employed would depend on the characteristics of the subscriber equipment. Packet switching would be used for all communications between hybrid switches. Several types of hybrid switches, with differing capabilities, could be developed for specific switch applications.

6.2.3 Distribution Requirements of Diverse TACS Elements

The future architecture, with the packet-switched network as its backbone, must serve TACS elements that have diverse information flow requirements. These elements include: operations and intelligence modules; support facilities; sensors, both ground-based and airborne; radios for communications with mission aircraft; and mobile subscribers. The information flow requirements for each element type and a discussion of how the concepts developed satisfy these requirements are provided below.

Figure 6-2 and a series of similar diagrams that will be presented illustrate the alternative concepts for the future architecture. It is important to recognize that these diagrams do not represent specific architectures, but only illustrate concepts. The larger, rectangular boxes in these figures represent ground-based TACS elements, including operations and intelligence modules, support facilities, ground-based sensors, airborne sensor interface stations, and ground/air radios. Mobile subscribers and a fighter aircraft are also shown.

The small, square boxes represent transmission and switching facilities. These facilities are equipped with packet switches. The solid lines running between boxes represent relatively short (less than 10 km) transmission links. The transmission media for these links could be metallic or fiber-optic cable, millimeter-wave radio, or laser-generated light waves. The lightning bolts on the figure represent longer transmission links. The media for these links could be line-of-sight or troposcatter microwave radio. Some of these transmission and switching facilities may be equipped with DSCS-compatible satellite terminals. DSCS is a multichannel SHF military satellite system. Our concepts assume that satellite capacity will be a shared resource available to all users of the packet-switched network. In the future TACS network, satellite links will be most beneficial when the complete switched network is not functioning, such as during the surge and build-up deployment phases or due to attrition. Satellite links offer the additional advantage of hiding the logical connectivity of the network. The use of airborne relays will be discussed later in this report.

The left side of these figures represents the rear area of a TACS deployment region, and the right side represents the forward area. The drawings are not to scale and path distances should not be inferred from the lengths of lines on the figure.

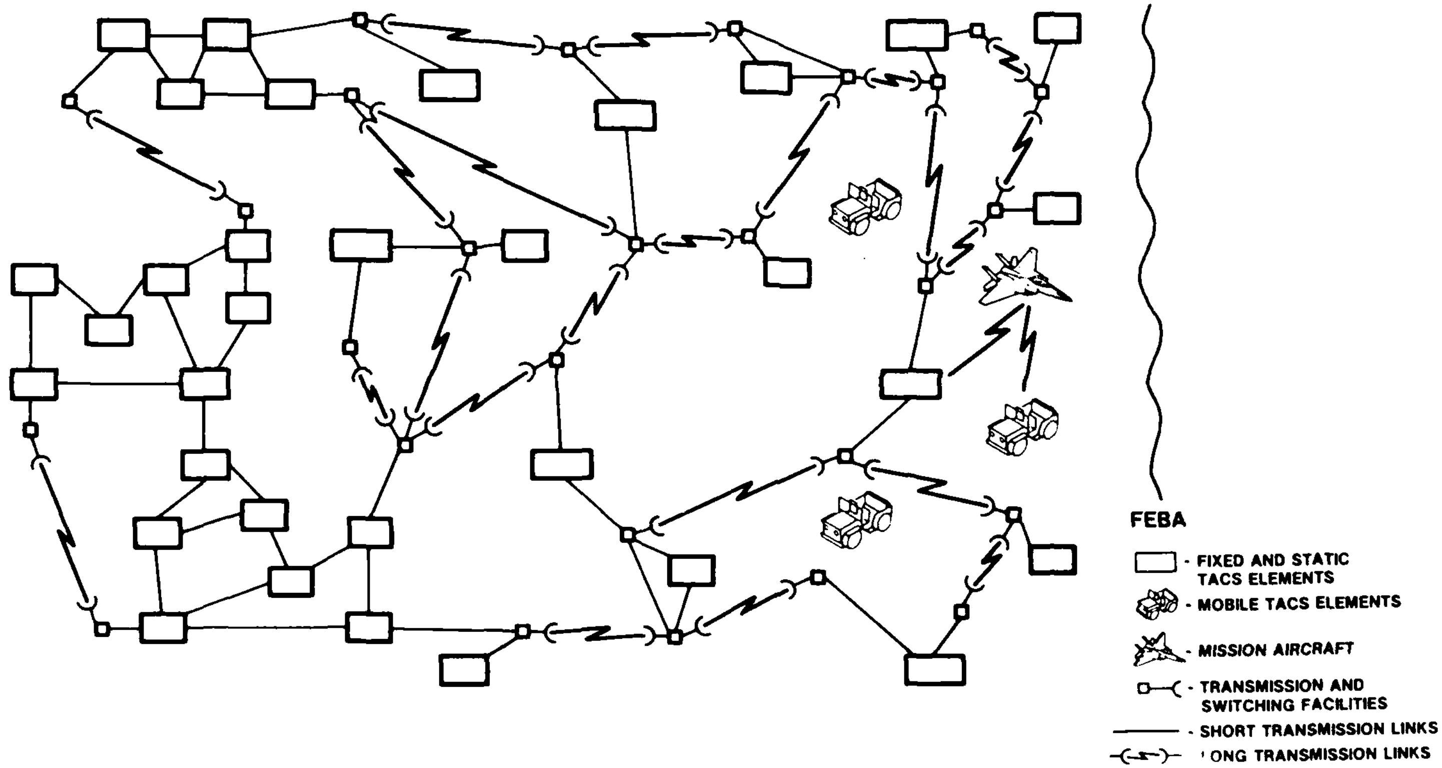


Figure 6-2. Illustrative Architecture, Network Structure

6.2.3.1 Operations/Intelligence Modules. The critical operations and intelligence functions will be performed in dispersed modules, which will be similar to the Modular Control Equipment (MCE). Each of these physically identical modules are assumed to possess the automated capabilities required to support any of several C^2 functions. The modules may be deployed separately for maximum dispersal of function to enhance survivability, or they may be organized into multiple-module facilities, such as a Control and Reporting Center (CRC). Even if the modules are organized into groups, they may be separated by several miles.

The personnel within these modules need to communicate with a variety of static, mobile, and airborne elements, including other modules. Equipping each module in the future architecture with a packet switch and associated transmission equipment will provide full network connectivity to each module. Thus, each module becomes an independent node in the switched network. This concept is more survivable than the current MCE concept in which only designated collocated elements provide switching and technical control capabilities. The new concept also provides maximum flexibility in deployment.

In today's TACS, some operations modules are deployed in the forward area along with their associated sensors and communications equipment. In the following sections of this report, sensor and radio configurations that allow the operations modules to remain in the rear area will be presented. Figure 6-3 depicts two groups of operations modules (OM) and intelligence modules (IM). The modules are shown only in the rear area of the deployment region.

6.2.3.2 Support Facilities. Other personnel are required to support the command and control activities. They perform the administrative, logistical, maintenance, and weather functions. In today's TACS, the same large circuit and message switches that serve operations personnel also serve support personnel. A more survivable concept that includes packet switches throughout each support area has been postulated. Each packet switch functions as an independent node in the network. If many subscribers are collocated in the same support facility, they could be linked in a local area network (LAN). In this event, the LAN would have to be interfaced with the facility's packet switch. A redundant interface between the LAN and a nearby switch would enhance the survivability of the connection.

A group of support facilities (SF) are shown in figure 6-4. These facilities, each of which is equipped with a packet switch, will be located in the rear area.

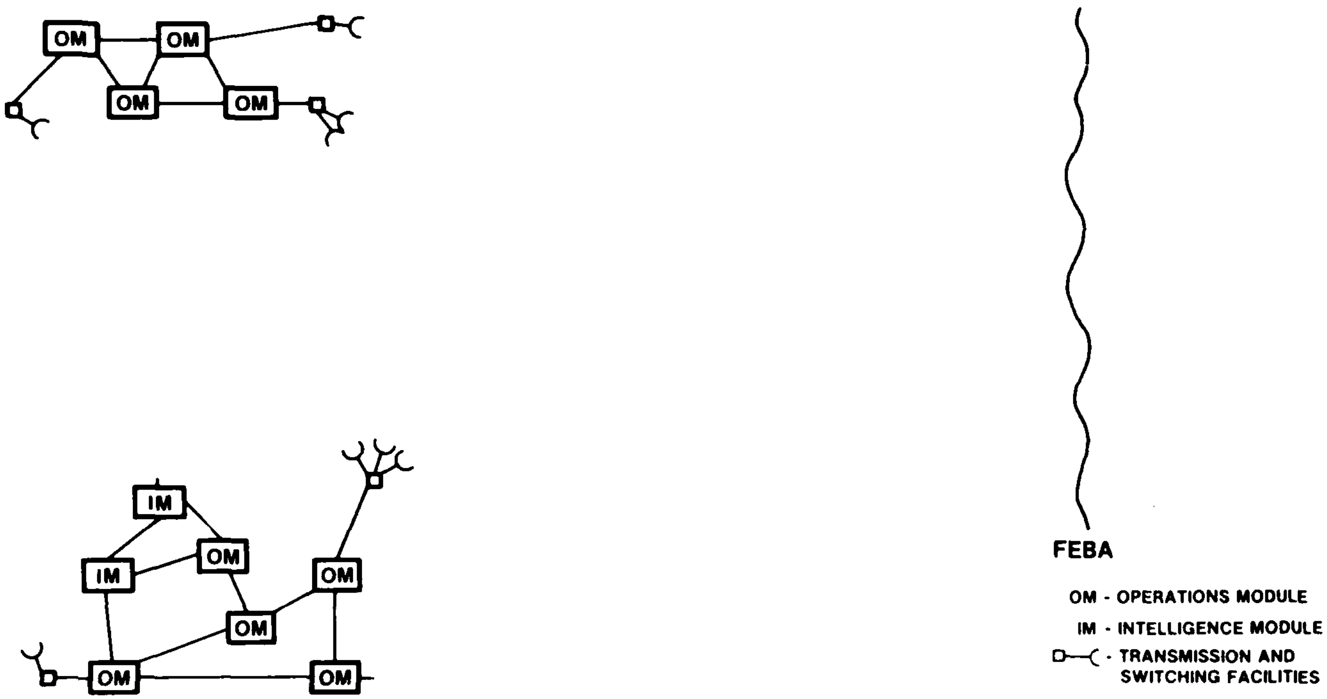


Figure 6-3. Operations and Intelligence Modules

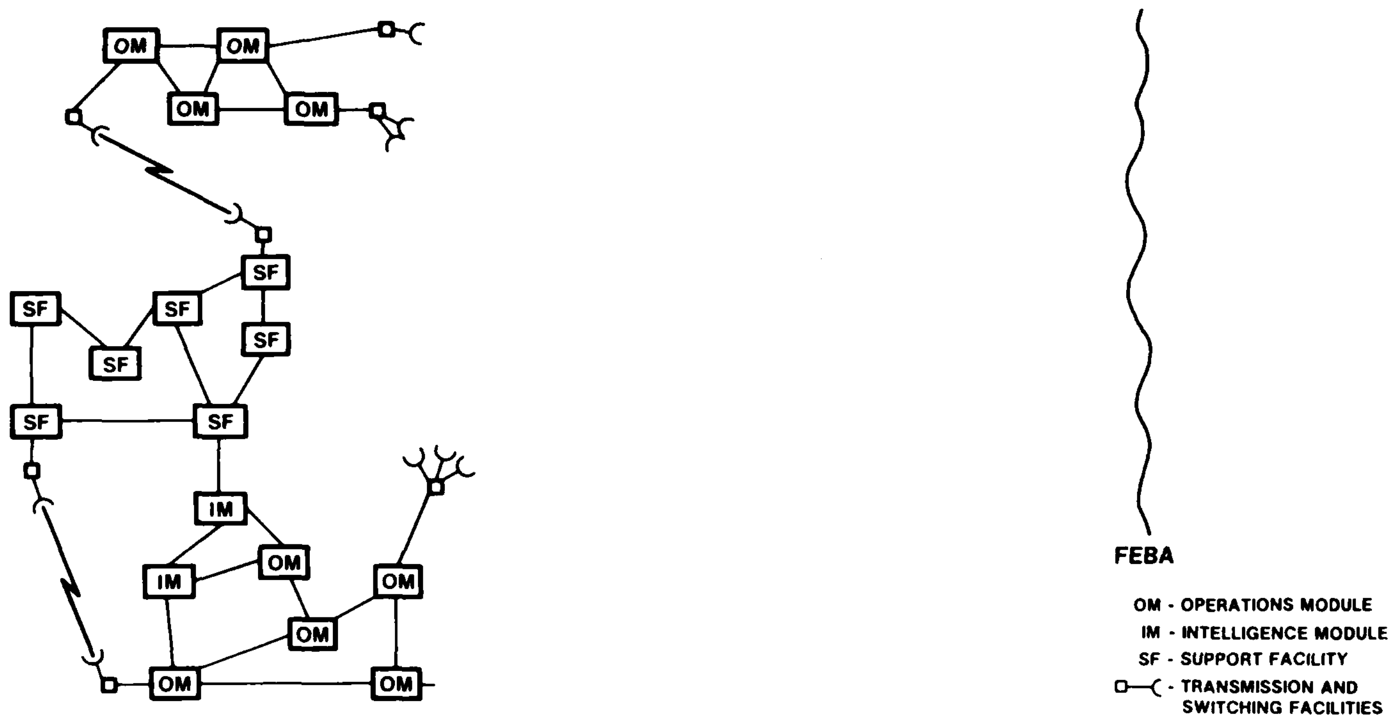


Figure 6-4. Support Facilities

6.2.3.3 Sensors. Three sensor deployment configurations, which represent a range of possible future deployments, were considered. The first configuration is similar to today's TACS in that ground-based sensors are dedicated to specific control facilities. Although the sensors and control facilities are paired in this configuration, it is assumed that the control facilities will be deployed only in the more secure rear area. The network will link the control facilities with their associated sensors. The tracking function is performed at the control facilities, which use the switched network to distribute the Recognized Air/Land Picture (RALP). The principal deficiency of this configuration is flexibility. It requires the sensors and control facilities to be deployed jointly. The destruction or disablement of a control facility would isolate its associated sensor from the remaining control facilities.

The second configuration also uses ground-based sensors, but the sensors are no longer dedicated to specific control facilities. In this configuration, the sensors are a shared resource available to all qualified users. The sensors perform the tracking function and broadcast information concerning tracks for which they are responsible on the switched network; therefore, the RALP is available to all subscribers of the network. Because the sensors are not dedicated to specific control facilities, the sensors and control facilities can be deployed independently.

The third sensor deployment configuration also uses the shared-resource concept, but both ground-based and airborne sensors are employed. The ground-based sensors provide coverage in the rear area and the airborne sensors provide forward-area coverage. The airborne sensors may be the receiving elements of a bistatic sensor system. This configuration is most appropriate when the forward-area terrain is not suitable for sensor deployment, or when enemy capabilities would limit the survivability of static sensors in the forward area.

If the sensors, be they ground-based or airborne, are not dedicated to specific control facilities, we postulate that each sensor will interface with the switched network. Therefore, each ground-based sensor should be equipped with a packet switch. Each airborne sensor will be assumed to be interfaced with the switched network at a designated ground station equipped with a packet switch.

Figure 6-5 shows ground-based sensors (S) dispersed throughout the TACS deployment region. This figure illustrates the first two sensor deployment configurations, as defined above. The third deployment configuration is illustrated in figure 6-6. Several air surveillance ground stations (ASGS), which provide the interface between the airborne sensors and the packet-switched network, are shown.

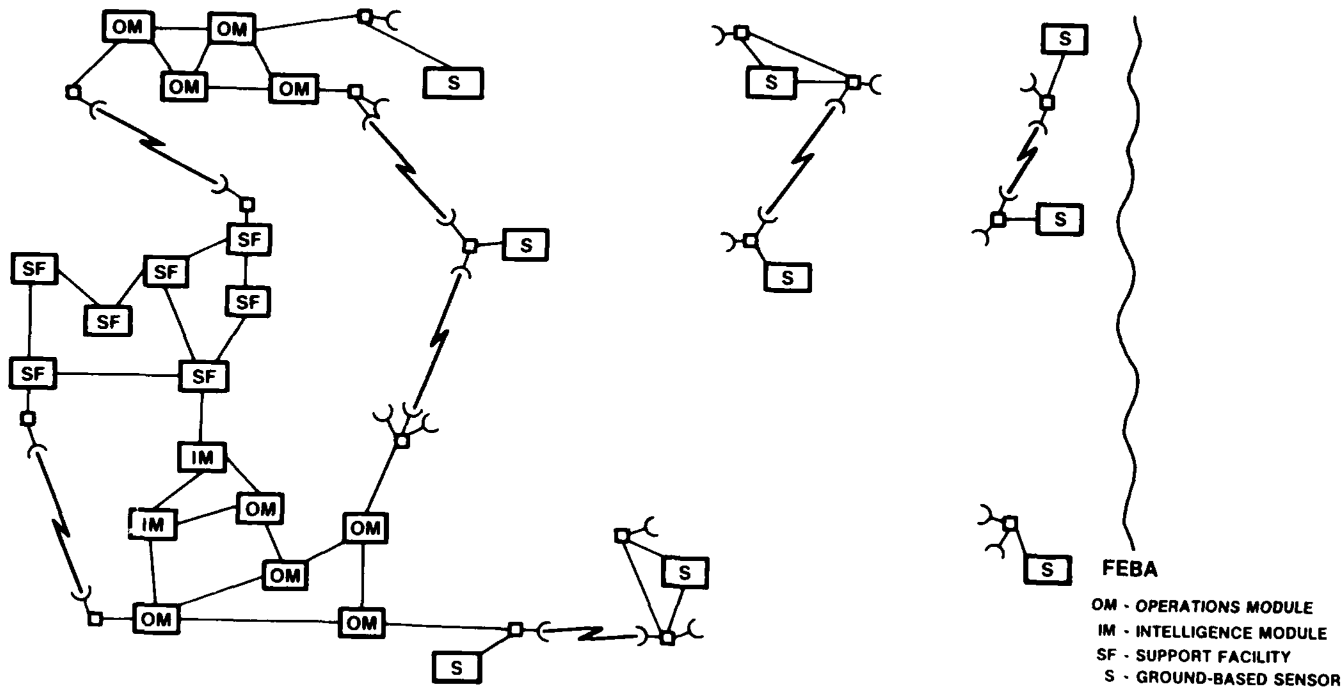


Figure 6-5. Ground-Based Sensors

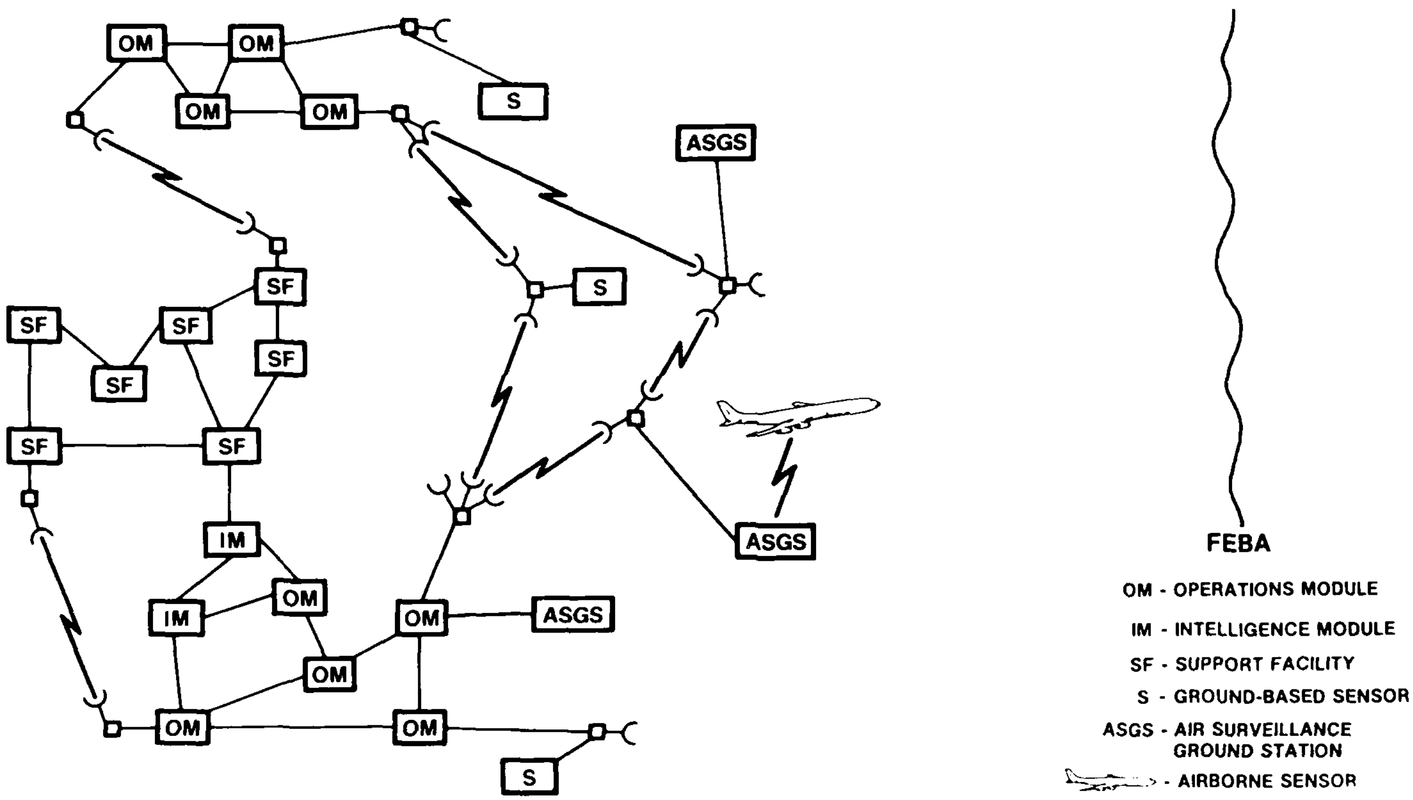


Figure 6-6. Airborne Forward-Area Sensors

6.2.3.4 Radios for Communications with Mission Aircraft. In today's TACS, ground-based radios are used to support communications between C^2 facilities and mission aircraft. Complements of radios are dedicated to and deployed with selected C^2 facilities. The radios used to support the future TACS requirements may include conventional HF, VHF, and UHF equipment; HAVE QUICK or EJS; JTIDS; and SINCGARS. The specific radios used depend on the type of equipment installed in the various aircraft with which communications may be conducted.

The future TACS architecture may include both ground-based radios and airborne relays. Airborne relays provide line-of-sight communications in environments where ground-based links would be too vulnerable or difficult to establish. They are also useful in a time period before ground-based links can be established, such as during the surge phase of a deployment.

6.2.3.4.1 Relationship between Radio and Sensor Deployment. Three sensor deployment configurations were discussed in section 6.2.3.3. In the third configuration, airborne sensors provide forward-area coverage, and ground-based sensors are used only in the rear area. This configuration would be chosen if the forward-area terrain were not suitable for sensor deployment, or if enemy capabilities in this region would limit the survivability of ground-based sensors. In this case, it would probably also be disadvantageous to use ground-based radios in the forward area. Airborne relays would then be required to provide forward-area communications coverage.

In summary, if sensors are not deployed in the forward area, then ground-based radios to support communications between static C^2 facilities and mission aircraft will also not be used in this area. Airborne relays and rear-area, ground-based radios will provide the necessary communications coverage. Conversely, if sensors are deployed in the forward area, airborne relays are not required because ground-based radios can be used throughout the deployment region.

6.2.3.4.2 Ground-Based Radios. Ground-based radios for communications with mission aircraft can be dedicated to specific control facilities or be a shared resource available to all qualified users. If the radios are a shared resource, the switched network should be used to relay information between the static facilities and the radios. An interface between each ground/air transmission system used (UHF, JTIDS, etc.) and the switched network is therefore required.

If the radios are shared, a user requesting the use of a radio should not have to indicate a specific radio facility, but only indicate the airspace of interest and the transmission system needed. The network should then establish communications between the user and a suitable radio. If communications between the ground-based user and the aircraft are

disrupted, the network should automatically reestablish communications, using another radio if necessary. The switched network must also be able to deliver messages, including those on emergency and common channels, originated by aircraft.

Dispersed ground-based, ground/air (G/A) radios are depicted in figure 6-7. This diagram is appropriate for deployment configurations in which unassigned ground-based radios (and sensors) are used in the forward area.

6.2.3.4.3 Airborne Relay Configurations. Two alternative airborne relay configurations have been examined. Each configuration includes Airborne Relay Platforms (ARPs) and ground-based Airborne Relay Interface Stations (ARISs), which serve as the interface between the airborne relays and C^2 facilities. An interface station may be a subsystem integral to a C^2 center, or it may be a separate facility. The interface stations provide the switching, multiplexing, antenna control, spectrum spreading, and any other capabilities needed for a particular relay configuration.

Each airborne relay is paired with a dedicated, ground-based interface station in the Ground Station/Platform Pairing (GSPP) configuration. The packet-switched network relays information between the interface stations and the C^2 facilities. A subscriber needing the use of a radio on an airborne relay sends a radio request message to the appropriate interface station. If a suitable radio is available, it is allocated to the requesting subscriber and retuned to the subscriber's assigned channel. Communications between an airborne relay and its interface station will take place using a multiplexed, digital data link. Transmissions between several ground-based subscribers and mission aircraft share each multiplexed link. Redundant interface stations are used to provide back-up communications in the event one or more of the interface stations are destroyed. Figure 6-8 depicts the GSPP airborne relay configuration.

Multiple interface stations can access the same airborne relay in the Ground Station/Operations Module Pairing (GSOMP) configuration. There are more interface stations in this configuration and each station serves fewer subscribers, such as those in a single operations module. An interface station might be installed in an operations module or might be in a separate module. The GSOMP airborne relay configuration is illustrated in figure 6-9.

When a subscriber in an operations module needs a radio on an airborne relay, he accesses the nearby interface station. The interface station then transmits a radio request message to the appropriate airborne relay. The request may be transmitted when it is received, or it may wait until the airborne relay asks for new radio requests. If a suitable radio is available, the airborne relay makes the assignment. If an interface station is inoperable, the subscribers assigned to it may access another interface station through the switched network.

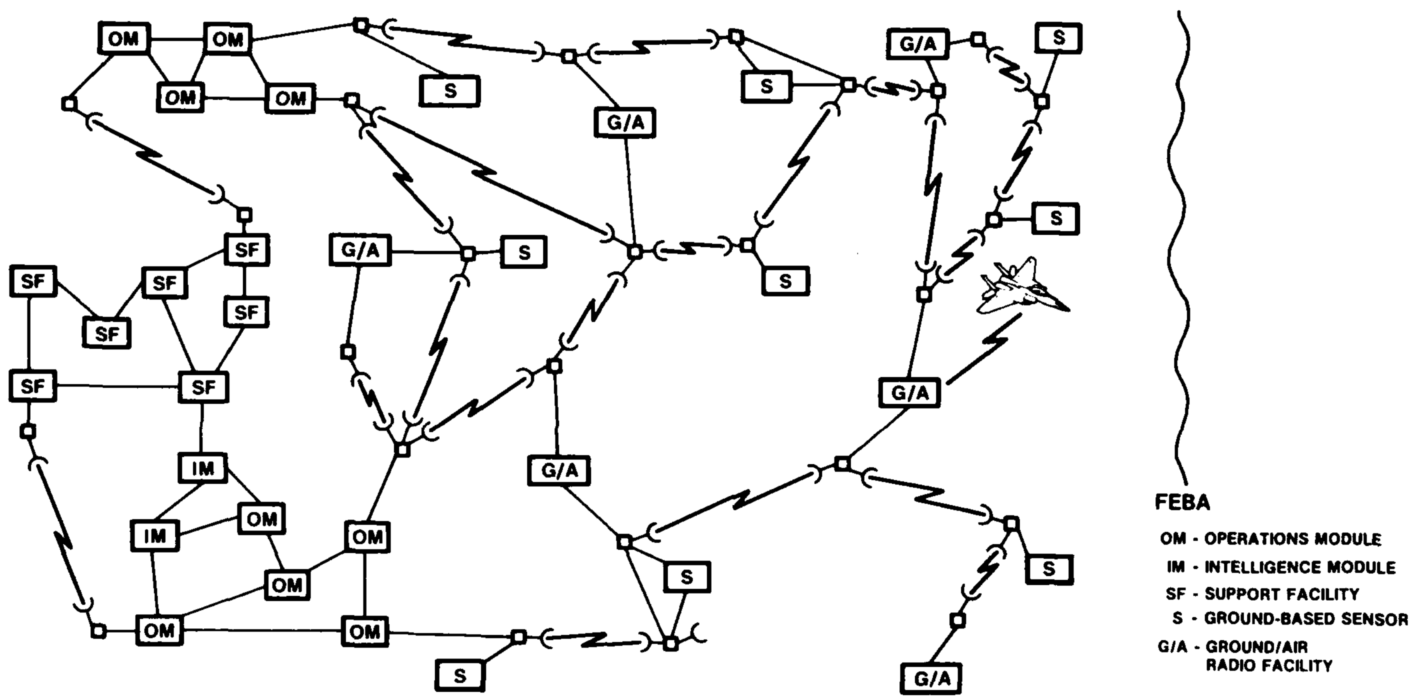


Figure 6-7. Radios for Communications with Mission Aircraft
Ground-Based Radios

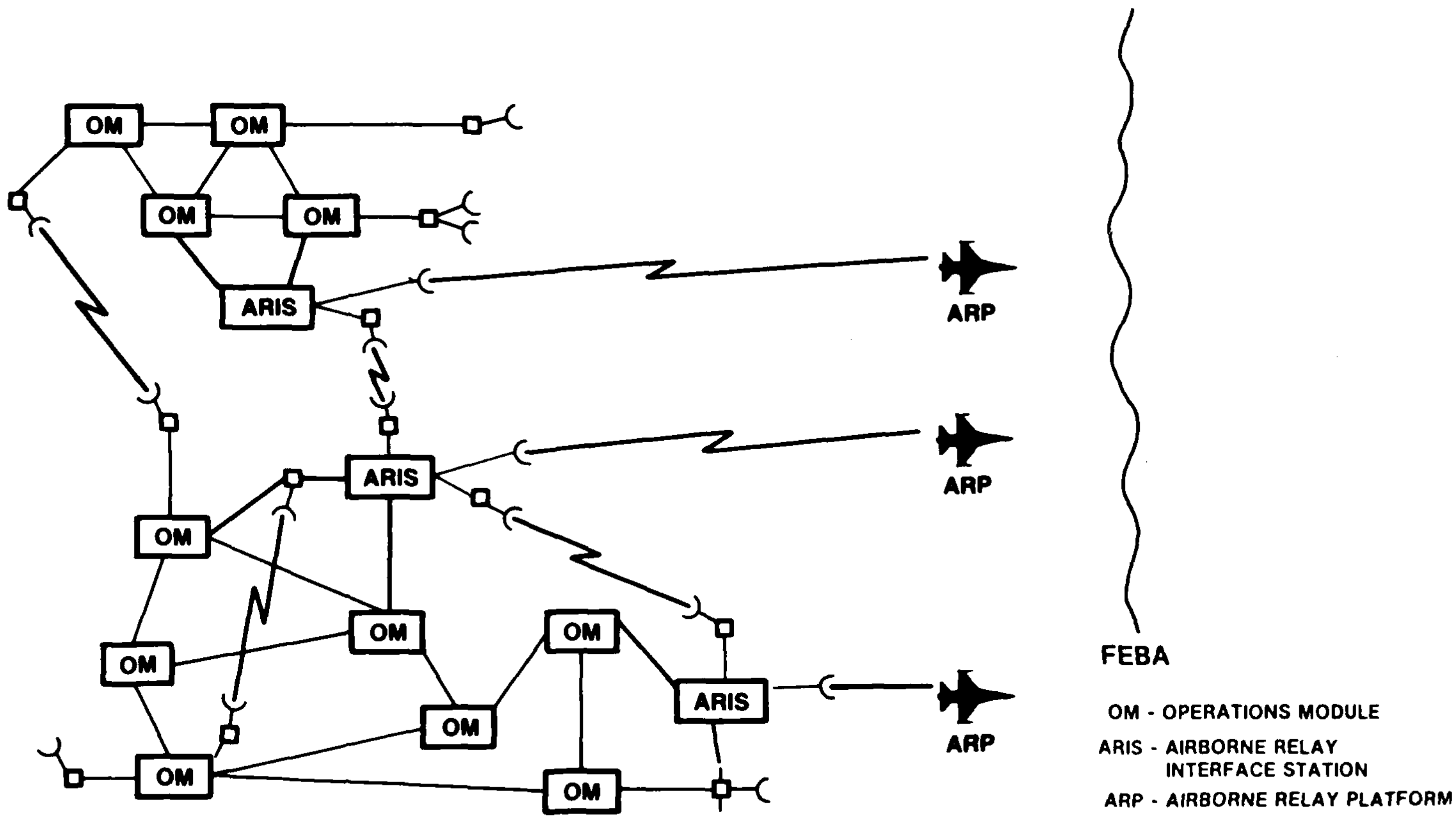


Figure 6-8. Radios for Communications with Mission Aircraft
GSPP Airborne Relay

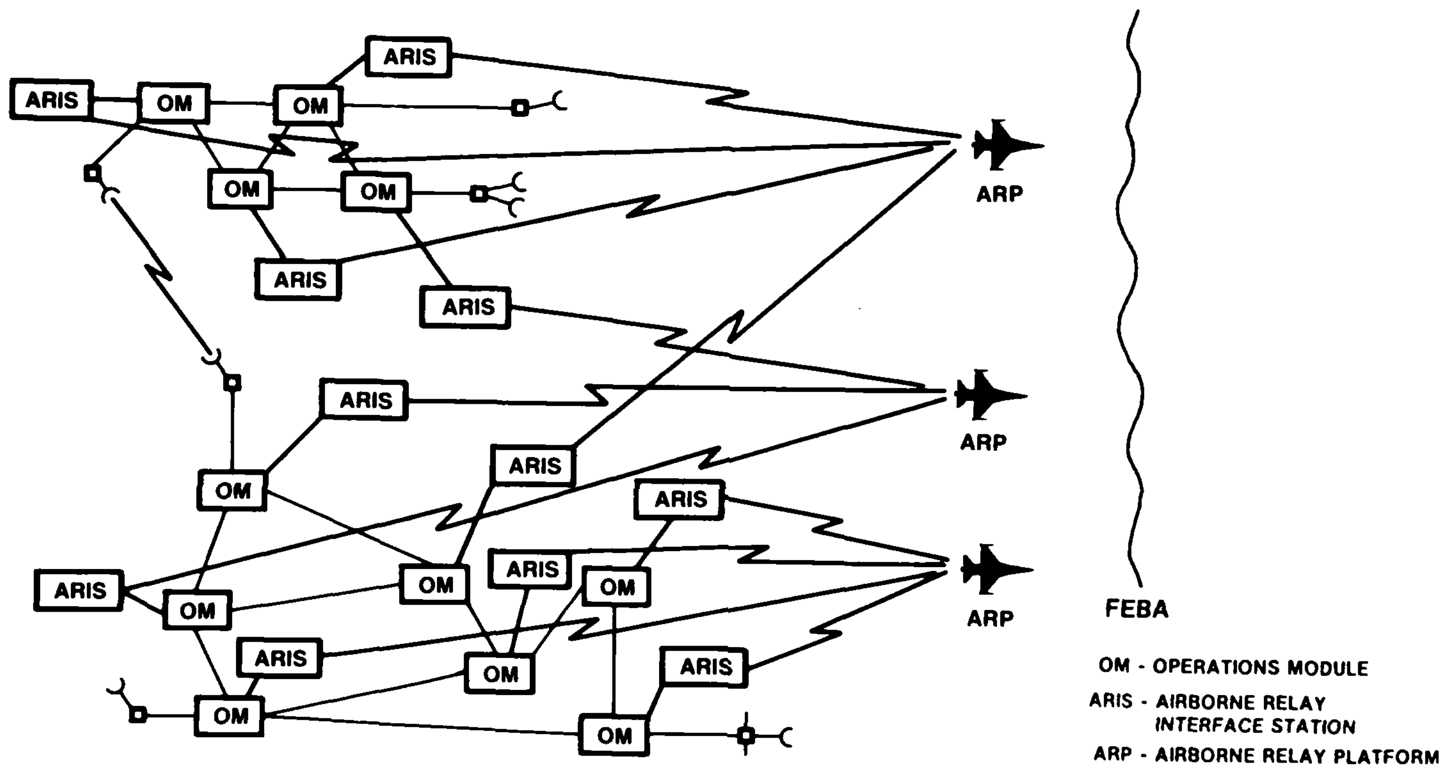


Figure 6-9. Radios for Communications with Mission Aircraft
GSOMP Airborne Relay

6.2.3.4.4 Airborne Relay Platforms. Candidate airborne relay platforms would include helicopters, airplanes, balloons, blimps, satellites, and gliders. Helicopters and airplanes can best satisfy the future TACS requirements because practical considerations eliminate the other alternatives. These considerations are outlined briefly below.

Balloons and blimps would be impractical due to lengthy deployment times, launching difficulties, and transport requirements. A polyurethane-coated nylon balloon capable of carrying sufficient weight (approximately 1500 pounds) at sufficient altitude (at least 10,000 feet) would require several hundred thousand cubic feet of helium and take several hours to reach altitude. Launching would require a large tower and could not occur in a high wind environment. Thus, balloons are impractical for tactical applications. Blimps are not appropriate for similar reasons.

Satellite relays were eliminated because most mission aircraft are not equipped with satellite-compatible antennas, and we have assumed that the aircraft will not be modified. In addition, a link from the fighter to the satellite would be extremely vulnerable to jamming because the jammer-to-satellite distance would be comparable to the fighter-to-satellite distance.

Glider aircraft could be used only if geographic conditions provided favorable air currents. In addition, the possibility of adverse weather conditions would make gliders extremely unreliable. Accurate station positions would be difficult to maintain as well.

6.2.3.5 Mobile Subscribers. Some of the elements in the TACS must be able to communicate while moving. Tactical Air Control Parties (TACPs), which play a key role in direct air support missions, will be deployed in the forward area. Combat Control Teams (CCTs), which conduct air traffic control operations where static facilities do not exist, can be deployed anywhere in the theater of operations. Once deployed, the CCTs can become essentially static. Other elements, such as new sensor systems, can also be mobile.

Mobile subscribers must communicate with static elements, aircraft, and other mobile subscribers. Present planning indicates that SINCGARS and other, more conventional radios will be used for links between mobile subscribers and aircraft. The MILSTAR EHF satellite system has been proposed to replace HF radio for the Immediate Air Request Network (IARN), which links a group of TACPs and an Air Support Operations Center.

We have identified two other alternatives for the IARN if MILSTAR is not available. If static elements are used throughout the deployment region, including the forward area, SINCGARS could be used to establish a link between each mobile subscriber and the switched network. Figure 6-10

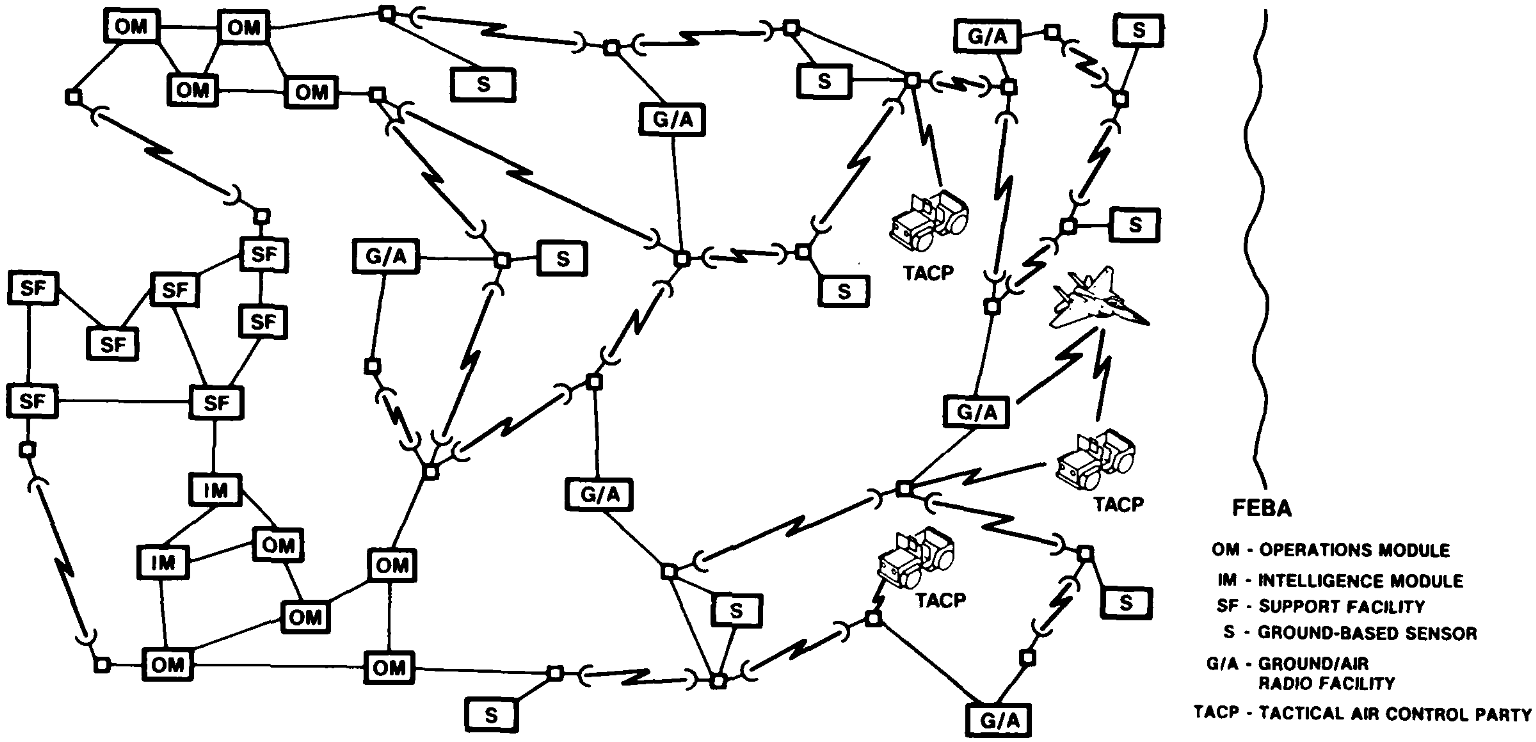


Figure 6-10. Illustrative Architecture
Ground-Based Air Surveillance

illustrates this alternative. A few representative TACPs are shown in the forward area. Since links between the TACPs and the switched network will be required if MILSTAR is not available, these links are included in the figure.

If static elements are not deployed in the forward area, an airborne relay could link the mobile subscribers with the switched network. Figure 6-11 illustrates this second alternative. The figure includes links between the TACPs and the airborne relays to be used if MILSTAR is not available. The same airborne relay could support mobile subscriber communications as well as communications with mission aircraft.

6.2.4 Message Routing

All information transmitted by the future TACS network will be processed by one or more packet switches. Each switch receiving a message, whether it is from a subscriber or from another switch, will determine if the message should be delivered to one or more subscribers of the switch, relayed to one or more other switches, or both delivered to local subscribers and relayed to other switches. The route that a message travels will depend upon factors such as network status, message length, and the number of subscribers that must receive the information. The routing algorithms will be a subset of a more comprehensive communications protocol, which will ensure that the necessary information flows through the network in a sufficiently reliable and timely fashion.

Both data and voice messages will need to be exchanged by the future network. Data message lengths will range from very short surveillance messages to very long data base updates. It is assumed that analog voice signals will be converted efficiently into digital bit streams and that these streams will be partitioned into packets for transmission. The analog/digital conversion and the packetization processes can be performed at a subscriber's terminal or at the switch serving the subscriber.

The end-to-end delay experienced by a voice packet should not be bothersome to a listener. The delay variance, which is a statistical measure of the per packet propagation delay differences, should also be as small as possible because delay variations have to be smoothed at the receiver by buffering the packets, which adds to overall delay.

Voice transmissions can make efficient use of the available channel capacity if packets are transmitted only when a speaker is actually talking. This approach may require that each voice packet contain an indication of the time it was transmitted. The time stamp allows a receiver to accurately estimate the lengths of silence periods.

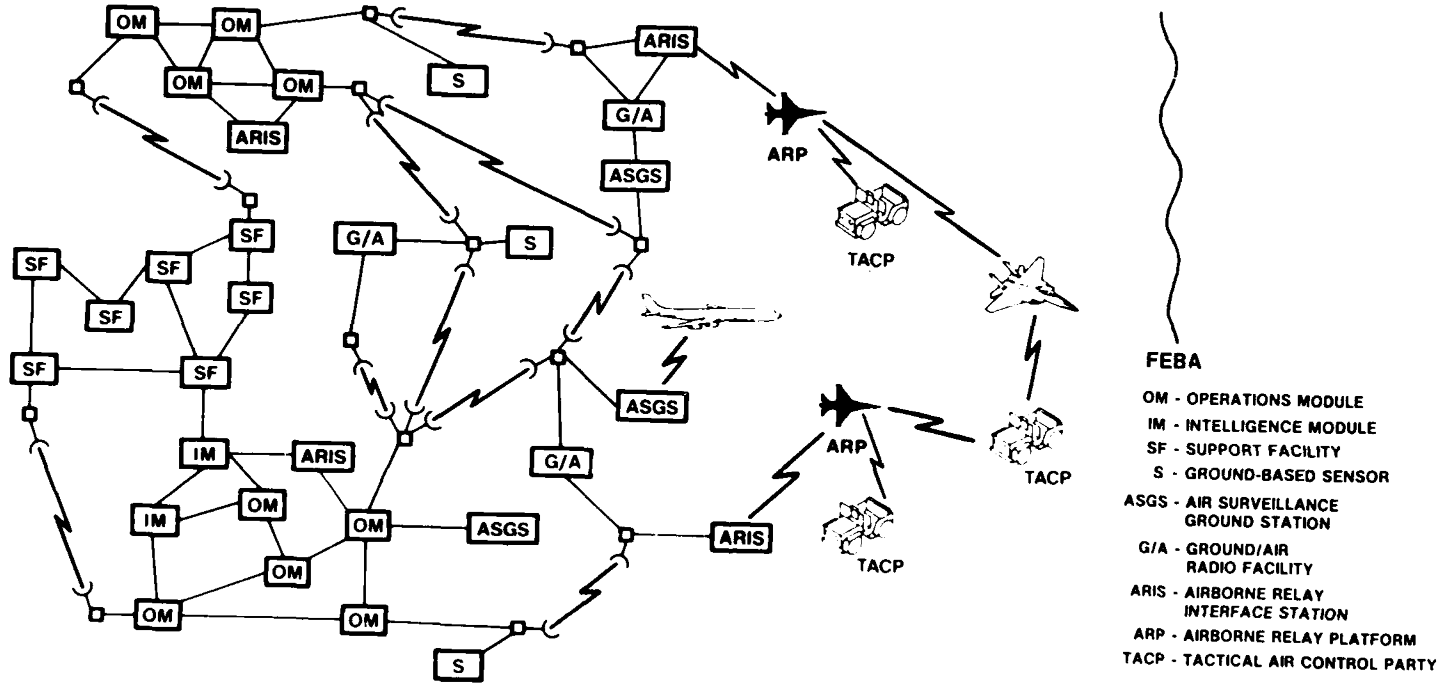


Figure 6-11. Illustrative Architecture
Ground-Based & Airborne Air Surveillance

It may be desirable to vary the lengths of the voice packets in response to changing network conditions. To minimize the packetization time and also the degradation in quality caused by a lost packet, the packets should be kept as short as possible. However, very short packets do not use the transmission resources efficiently since a fixed amount of overhead information must be included in each packet.

Information flow between static facilities is discussed in section 6.2.4.1. Communications between static facilities and mission aircraft is addressed in section 6.2.4.2. Communications with ground mobile subscribers is the subject of section 6.2.4.3. Since TACS elements will also need to communicate with external networks, the use of gateways is considered in section 6.2.4.4. Several possible approaches for distributing current network connectivity information are identified in section 6.2.4.5.

6.2.4.1 Communications between Static Facilities. All static facilities will be equipped with or have access to a packet switch. A subscriber wishing to transmit a packet will deliver it to a switch and from there the network will deliver it to the intended destination(s). Routing algorithms that depend on the number of intended destinations will distribute efficiently the diverse types of information characteristic of the future TACS. The routing of information to a single destination is discussed in section 6.2.4.1.1. Routing to a limited number of destinations is examined in section 6.2.4.1.2, and the broadcast routing of information to all accessible switches is considered in section 6.2.4.1.3.

6.2.4.1.1 Single Source to Single Destination. As discussed in appendix B, there are two principal algorithms used to govern the distribution of information between a pair of subscribers in a packet-switched network. In the datagram algorithm, each packet of a multiple-packet message is routed independently. Short messages, comprising no more than a few packets, are distributed efficiently by the datagram algorithm. Longer messages, including voice transmissions, are distributed more efficiently by the packet virtual circuit (PVC) algorithm, which establishes an end-to-end circuit through the network for each message. In the PVC algorithm, every packet of a multiple-packet message is routed along the same set of transmission links.

As an example of the information flow process, one possible route for information to travel between a sensor in the forward area and an operations module in the rear area is shown in figure 6-12. The information is relayed through several transmission facilities equipped with packet switches, but not operating TACS elements (modules, support facilities, sensors, etc.) with the exception of some modules located near the communicating operations module.

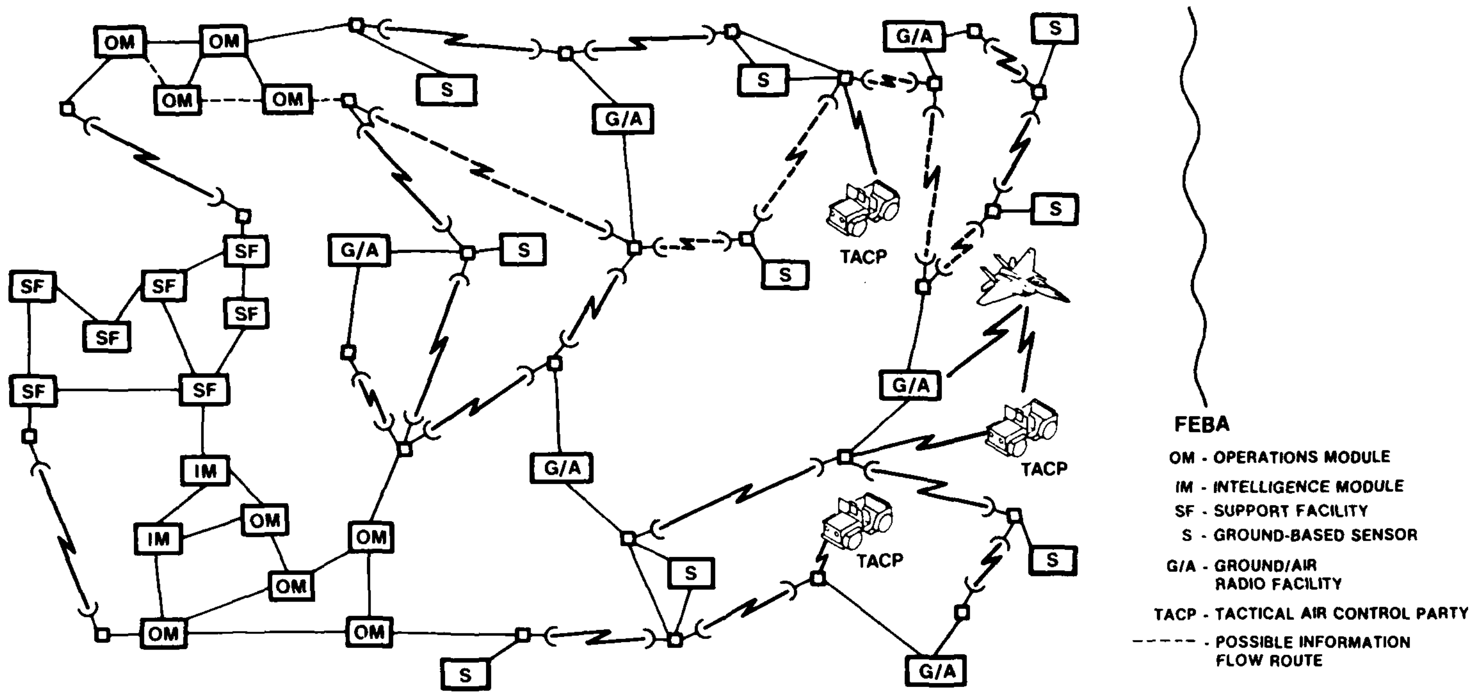


Figure 6-12. Single Source to Single Destination Routing Example 1

In figure 6-13 information is shown flowing between the same sensor and module as in the previous example. However, the information is now routed through a ground/air (G/A) radio facility equipped with a packet switch. This diagram shows that providing TACS elements with switches increases the number of routes for information to travel.

As previously discussed, some of the transmission and switching facilities in the future architecture may be equipped with DSCS-compatible satellite terminals. Figure 6-14 illustrates one possible use of these terminals. The figure shows information being routed via the switched network from a forward-area sensor to a facility equipped with a satellite terminal. The information is relayed via the communications satellite to another facility equipped with a satellite terminal. The switched network delivers the information to an operations module.

6.2.4.1.2 Single Source to a Few Destinations. A significant portion of the time-sensitive information in the TACS must be distributed to multiple destinations. If the number of destinations is very large, it may be most efficient to route the information via the broadcast algorithm that will be described in the next section of this report. If the number of destinations is small, the information can be routed independently to each destination using the single-source-to-single-destination techniques. However, this may not be the most efficient approach. For example: consider a subscriber served by a switch A who wishes to send a message to subscribers served by switches B, C, and D. Assume the switches are serially linked by the network, as shown in figure 6-15, such that switch A is linked to switch B, which is linked to switch C, which is linked to switch D. If a single-source-to-single-destination technique is employed, switch A will send the message independently to each of the three specified destination switches. However, switch B will receive the identical message three times; one of the transmissions will be intended for switch B's subscribers and the two other transmissions will be intended for switches C and D. Similarly, switch C will receive the identical message twice.

A more efficient routing algorithm would not send a message over a particular transmission link more than once. Using the example above, switch A, as before, first determines the best outgoing transmission link for a message to travel to switches B, C, and D. If this link is the same for all three destinations, the message is sent only once, but all three intended destinations are listed as addressees. When the message reaches switch B, the switch determines that the message requires further relaying in addition to delivery to local subscribers. The switch then retransmits the message with switches C and D listed as destinations.

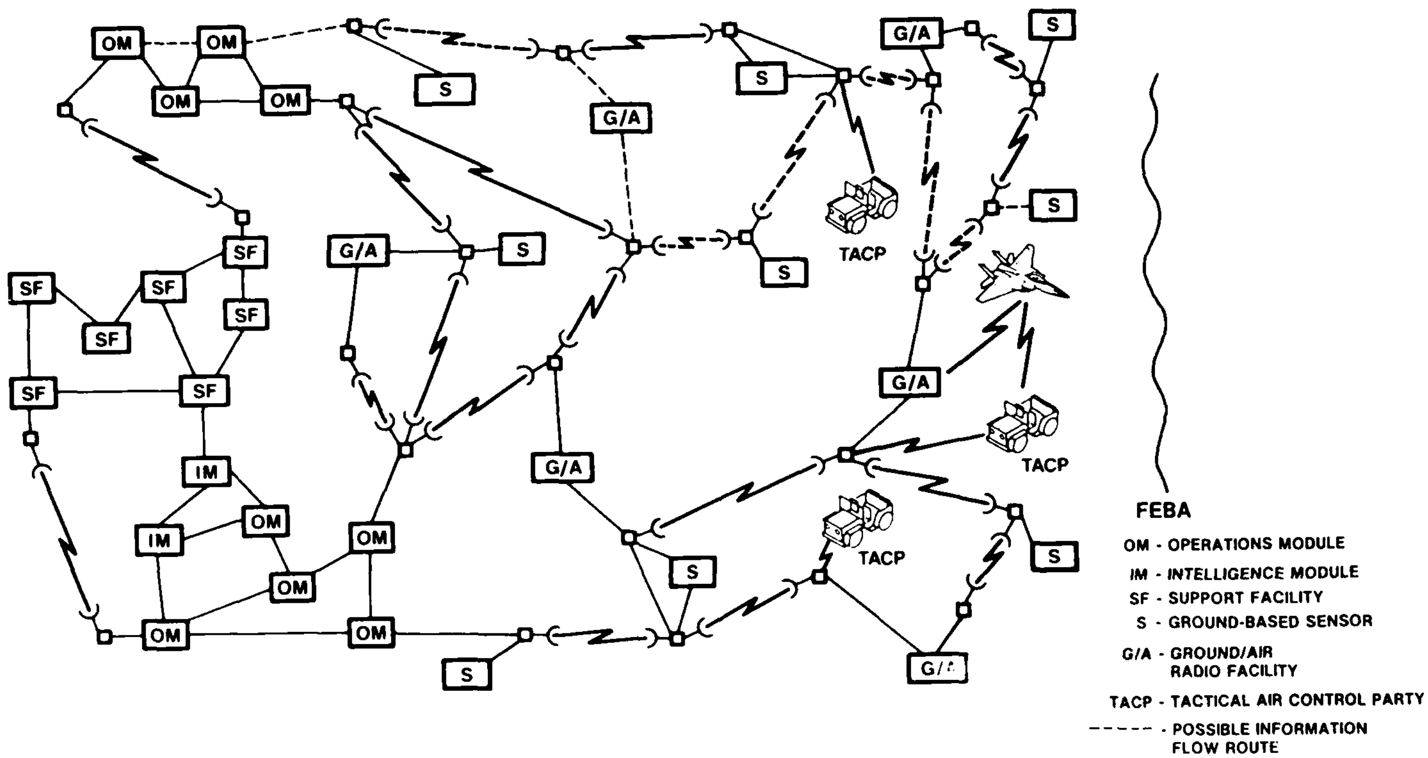


Figure 6-13. Single Source to Single Destination Routing
Example 2

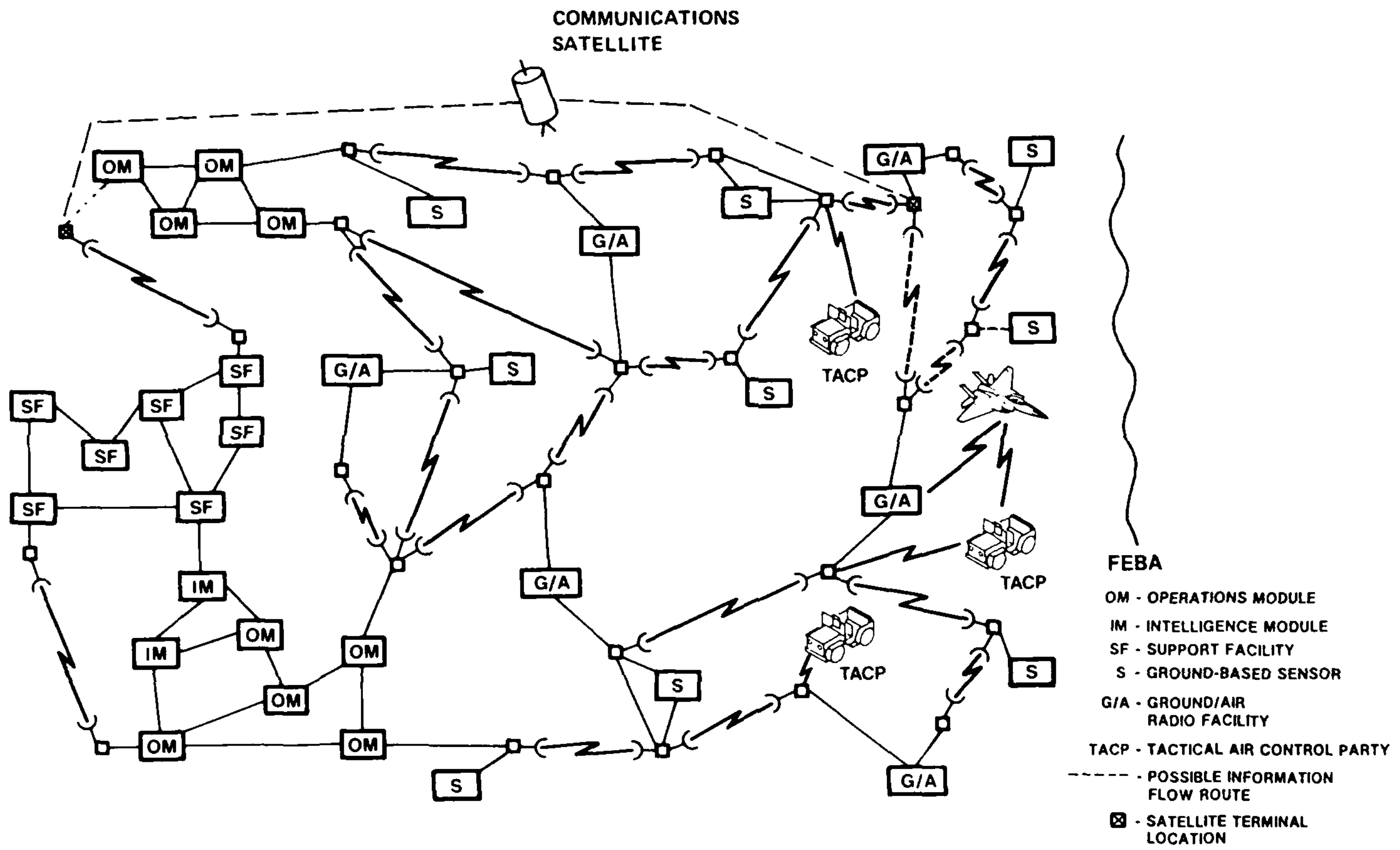


Figure 6-14. Single Source to Single Destination Routing
Example 3

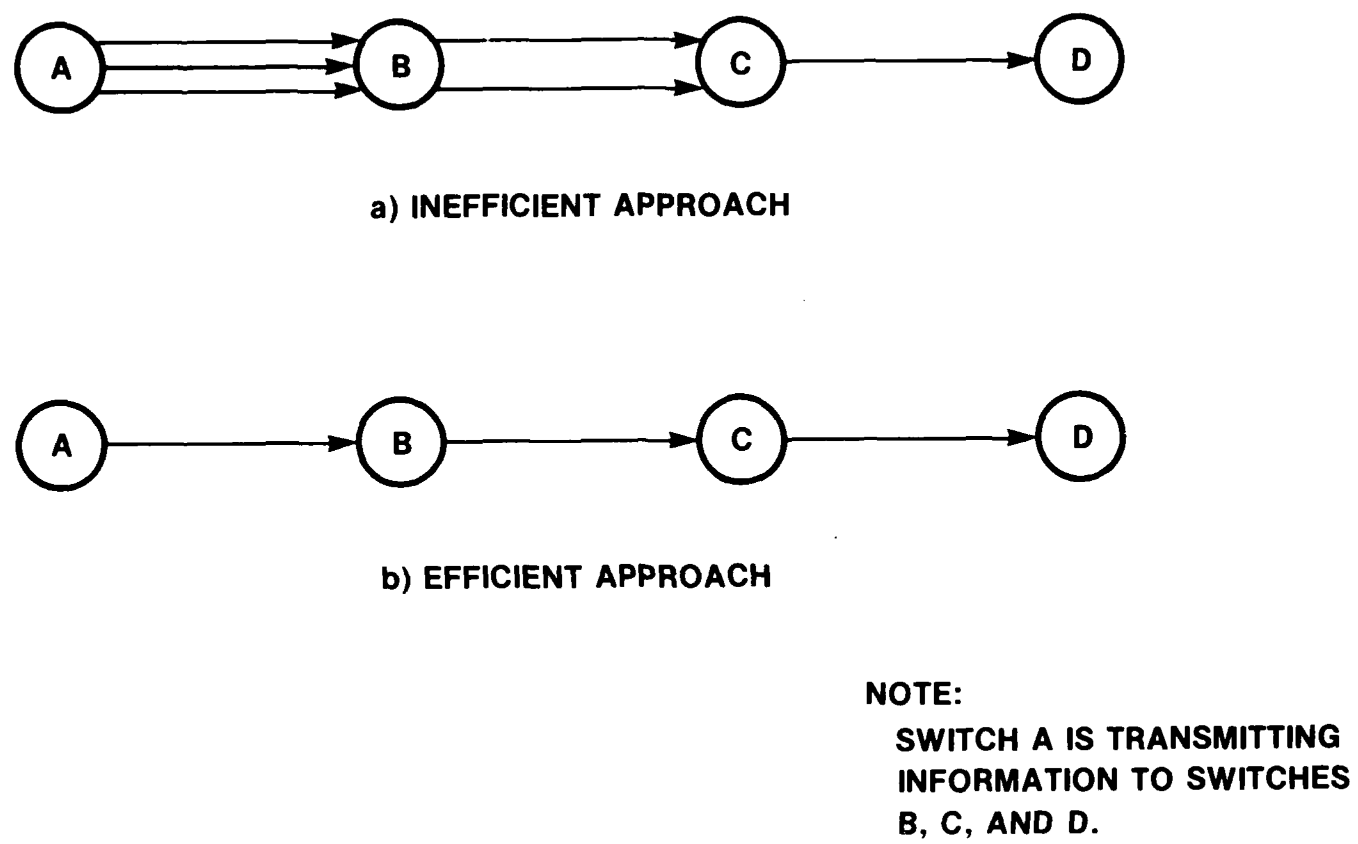


Figure 6-15. Multiple Destination Routing Illustration

If a network subscriber wishes to send a long, multiple-packet data message to several destinations, the switch serving the transmitting subscriber will attempt to set up a virtual circuit to each switch that serves an intended destination. Only one virtual circuit will be established to each destination switch, regardless of the number of subscribers served by the switch that must receive the information. The virtual circuits will be established in such a way that a message is not sent over a particular transmission link more than once.

A voice conference call can be implemented by having one participant direct the network to establish a virtual circuit between each pair of a user-specified set of participants. Packet virtual circuits do not use network capacity unless information is actually being transmitted. Therefore, to minimize network loading, only one participant should be allowed to transmit voice packets at a given time. A distributed control algorithm at each switch can determine the speaker "having the floor" at a given moment. The control algorithm should also allow new participants to enter the conference and existing participants to drop out. As with the other types of messages intended for multiple destinations, the voice packets should not be sent over a particular transmission link more than once.

6.2.4.1.3 Broadcast Routing. A significant portion of the time-sensitive information must be distributed to multiple destinations. If the number of destinations is small, the information can be routed using one of the algorithms discussed previously. However, if the number of destinations is large, a broadcast routing algorithm may be the most efficient approach.

A broadcast routing algorithm sends a message to every switch, whether or not the switch requires the information. This approach ensures that each user that does require the information will receive it, as long as at least one tandem combination of links is functioning between the information source and each recipient. Broadcast routing uses network capacity extravagantly and is therefore inefficient for distributing information to only a few users.

To demonstrate broadcast routing, assume that switch A is directly linked to switches B, C, and D, as shown in figure 6-16. If switch A receives a packet to be broadcast from one of its local subscribers, switch A transmits the packet to switches B, C, and D. If switch A receives a broadcast packet from switch B, switch A verifies that it did not previously receive the packet and then retransmits the packet to switches C and D. If switch A had received the packet previously, the new packet is not retransmitted. The packet propagates in this manner throughout the network.

Figure 6-17 illustrates the broadcast routing process. The information is shown traveling on every link to every switch.

a) SWITCH A RECEIVES A PACKET TO BE BROADCAST FROM ONE OF ITS LOCAL SUBSCRIBERS

b) SWITCH A RECEIVES A PACKET TO BE BROADCAST FROM SWITCH B

Figure 6-16. Broadcast Routing Illustration

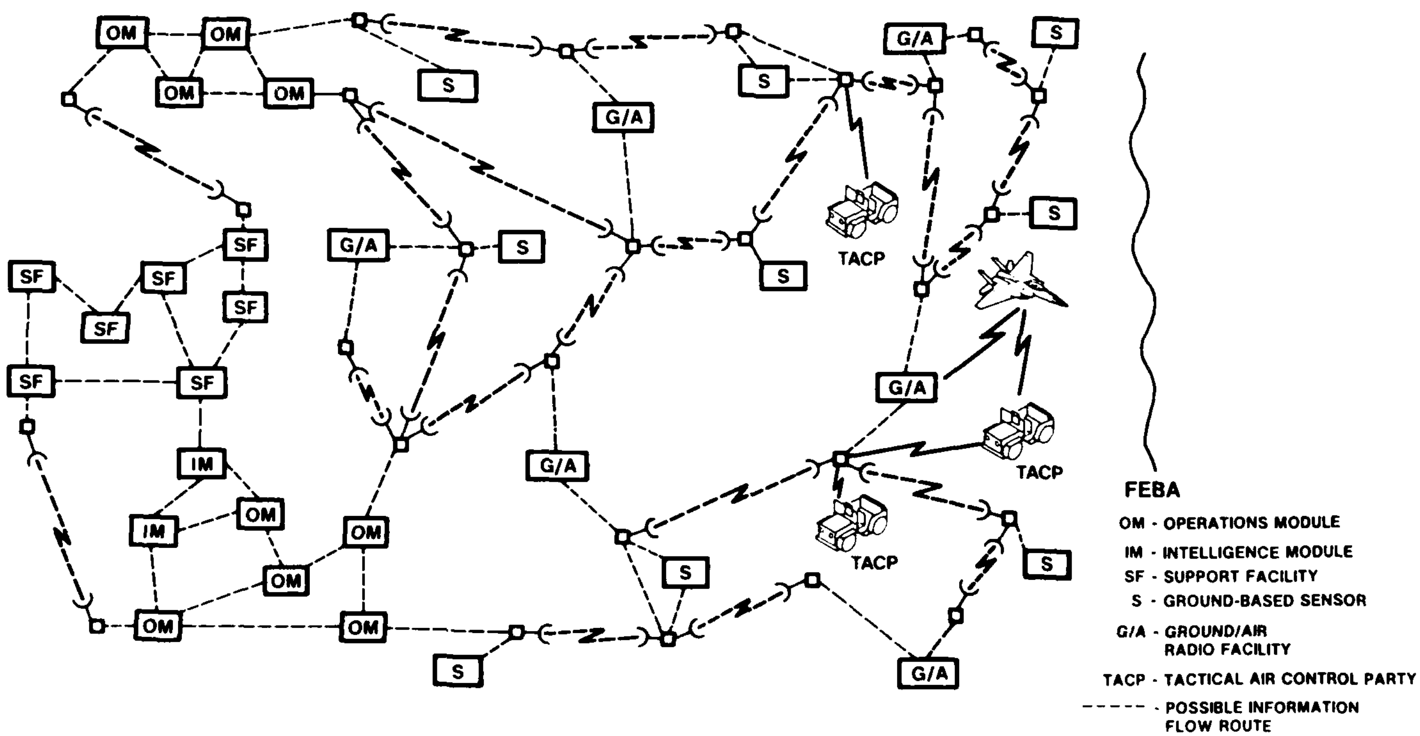


Figure 6-17. Broadcast Routing Example

6.2.4.2 Communications with Mission Aircraft. As previously described, the use of both ground-based radios and airborne relays has been postulated to support communications between static facilities and mission aircraft. The ground-based radios can be dedicated to specific control facilities or be a shared resource available to all qualified users of the packet-switched network. The airborne relays are assumed to be interfaced with the static TACS facilities through ground-based interface stations. One or more interface stations, depending on the configuration chosen, will be used with each airborne relay. In the ground station/platform pairing (GSPP) configuration, each interface station is associated with single airborne relay and is linked to the switched network. In the ground station/operations module pairing (GSOMP) configuration, each interface station is associated with an operations module and the switched-network interface is optional. Airborne relays are not required if ground-based radios can be used throughout the deployment region.

Some of the radios used to support communications with mission aircraft must be dedicated to emergency and common channels. The network must ensure that a message transmitted on one of these channels by an aircraft is delivered to C^2 facilities that will respond to it. Broadcasting the information will guarantee that each user who can respond will receive the message, as long as at least one tandem combination of links is functioning between the information source and each recipient. However, if several radios receive the same message on an emergency or common channel and each broadcasts the information on the switched network, the network will be excessively loaded. To minimize the loading, each packet switch in the network should be able to identify identical voice messages, so that each message is only retransmitted by that switch once.

We considered a typical mission involving aircraft and mission controllers to determine how radios that are not dedicated to specific control facilities could be used in the future architecture to support the mission. The step-by-step procedure is outlined below. In this discussion, it is assumed that the mission controller has no radios currently assigned to him.

> One or more aircraft assigned to a common mission are scrambled, and the assigned mission controller is notified. The scramble order indicates the assigned radio channels.
>
> The controller directs his computer to initiate a request for a particular type of radio using a specified channel that can provide communications coverage in the region that will be occupied by the aircraft during all or part of the mission. This step may occur before the aircraft are scrambled.

The controller's computer, based on information provided by the network, formulates a list of ground-based radios and/or airborne relays that can provide suitable coverage. If accurate and timely information concerning radio status is available, the list can be limited to those radios known to be available. If the controller indicates a preference for an airborne relay over a ground-based radio, the list should indicate this request.

If only ground-based radios are used:

> The controller's computer instructs the network to attempt to establish a packet virtual circuit (defined in appendix B) between the controller and one of the radios on the list.

If both ground-based radios and airborne relays in the GSPP configuration are available:

> The controller's computer instructs the network to attempt to establish a virtual circuit between the controller and either a listed ground-based radio or an airborne relay interface station (ARIS) paired with a listed airborne relay. In this configuration the ARIS is accessible through the switched network.

If both ground-based radios and airborne relays in the GSOMP configuration are available:

> The controller's computer either instructs the network to establish a virtual circuit between the controller and a listed ground-based radio, or the controller's computer accesses the ARIS assigned to the controller's operations module for relaying to a listed airborne relay. The ARIS in this configuration is accessible through either the switched network or dedicated lines.

If a desired radio is unavailable or inaccessible, a second radio on the list described above is chosen. The controller's computer then automatically attempts to establish communications with this second radio using one of the procedures listed above. This process repeats until communications with a suitable radio are effected.

The radio is set to the controller's assigned channel.

The controller is informed that a suitable radio has been assigned to the mission and is now available.

The aircraft, when airborne, contacts the controller on the assigned channel.

If information does not flow between the controller and the radio for some fixed period of time, a warning message is sent to the controller. If the controller does not request the continued use of the radio, it is released.

If the aircraft leaves the coverage region of the radio being used, or if communications are otherwise disrupted, communications between the controller and the aircraft will be reestablished automatically using another radio. The controller may anticipate changing coverage requirements and secure the use of one or more additional radios prior to the time that they are actually needed. If the controller has secured the use of multiple radios, possibly to support several missions, he must be able to designate the radio that he wishes to use for each transmission.

To hand the mission over to a new controller, the original controller sends a handover request message to the second controller. Upon receipt of this message, the second controller requests the appropriate radios, as described above. When access to the communication resources has been ascertained, the second controller sends a message to the original controller accepting the handover. The original controller notifies the aircraft.

6.2.4.3 Communications with Mobile Subscribers. As previously discussed, the MILSTAR EHF satellite system has been proposed to replace HF radio for the Immediate Air Request Network (IARN), which links a group of TACPs and an Air Support Operations Center (ASOC). If the proposal is implemented, a MILSTAR-compatible terminal will be required at each TACP and ASOC. The information flow with MILSTAR may be independent of the switched network.

Two alternative communications configurations to support the IARN if MILSTAR is not available were previously discussed. The first alternative would be appropriate only if the TACS deployment includes static facilities, such as sensors or radios for communications with mission aircraft, in the forward area. The second alternative is appropriate if static facilities are not deployed in the forward area.

The first alternative uses SINCGARS to link the dispersed mobile subscribers with the packet-switched network for communications between mobile subscribers and communications between mobile subscribers and static subscribers. This approach would give each mobile subscriber full network connectivity. The subscriber-to-network interface can be accomplished at any site equipped with a packet switch. Several interface points will be required to ensure connectivity with the widely dispersed mobile subscribers. The network will need to determine the interface point nearest each mobile subscriber and be able to adapt automatically if a mobile

subscriber leaves the coverage region of one interface point and enters the coverage region of a second interface point. Once the link between a mobile subscriber and the network has been established, messages can be routed to and from the mobile subscriber in a manner identical to that for static subscribers.

The second alternative for the IARN involves the use of airborne relays. Since one airborne relay may not have line-of-sight to ground locations throughout a TACS deployment region, several airborne relays may be required to link the TACPs. The network must then determine which relays must be used to access which TACPs.

6.2.4.4 Communications with External Networks. The TACS needs to exchange information with various external networks. These networks will probably employ communications protocols that differ from those postulated for the future TACS network. Even if a particular external network uses packet switching, there may be significant differences between the formats and protocols used by the external network and the TACS network. A gateway is therefore required to resolve the differences between the future TACS network and each external network with which information will be exchanged. The gateway will receive messages from transmitting subscribers on one network, buffer them and resolve the differences, and retransmit the modified messages to their intended destinations on the second network. Survivability considerations dictate that several dispersed gateways should be used for each external network.

6.2.4.5 Network Connectivity Distribution. The transmission efficiency of the network is enhanced if each packet switch can learn the network connectivity continually and adapt automatically to changes in it. If the shortest path between two locations is defined to be the route that traverses the fewest switches, each switch can deduce, from the connectivity data, the shortest path to every other switch. Alternatively, the shortest path can be defined to be the route that will relay a message in the least time. To deduce the shortest path under this definition, a switch must be informed of the expected delays on each switch-to-switch link in the network.

Each switch should also have information indicating the subscribers served by every other switch. With this information, a switch attempting to send a packet to a specified subscriber can route the packet to the switch that can complete delivery. The subscribers will be data and voice users functioning in operations modules, intelligence modules, support facilities, ground-based sensor facilities, ground stations interfacing with airborne sensors, ground-based radio facilities supporting communications with mission aircraft, ground-based stations interfacing with airborne relays, mobile C^2 facilities, and external network gateway locations.

There are several possible approaches for distributing the current connectivity information. Each switch could broadcast information describing its own connectivity periodically, when requested, or when changed. Alternatively, each switch could broadcast information describing the complete network connectivity, as understood by that switch. One other possibility would be to have each switch exchange connectivity information only with the other switches with which it is directly linked. An algorithm may also be developed to allow the switches to learn the connectivity of the network by examining connectivity information appended to message packets. This latter approach would reduce the number of messages relayed by the network, but the amount of overhead added to each packet would increase.

6.3 ASSESSMENT OF ALTERNATIVE CONCEPTS

The distributed network structure postulated for the future TACS architecture satisfies many of the goals. Most significantly, the network can deliver information successfully in a high attrition environment. Dispersing packet switches throughout a deployment region reduces the network's vulnerability to disruptions caused by the destruction of a few switches. The fact that the network structure is nonhierarchical ensures that there will be several routes for information to travel between switches, which reduces the network's vulnerability to disruptions caused by the destruction of a single centralized facility. Each switch performs the technical control function by continually monitoring network status and determining the best route for information to travel. The switches can adapt the network automatically to changing connectivity. Since current information concerning the network status is available throughout the deployment region, network planning activities can take place at numerous locations. A group of operations modules will no longer need to share a technical control facility, the destruction of which would severely disrupt information flow to the modules.

Packet switching satisfies the transmission efficiency goal because it can distribute a mix of short- and long-length, voice and data messages in an efficient manner. A packet switched network can therefore offer the greatest usable capacity to its subscribers, relative to other switching technologies. The timely information delivery goal is satisfied because packet switching has good message delay statistics for diverse types of information.

The distributed network improves survivability although some vulnerabilities remain. The principal deficiency remaining is the susceptibility of transmission links to detection, location, and jamming. Troposcatter links, required for long paths, are particularly easy to detect and thus locate and disrupt because of the high transmitter powers used. Therefore, it is expected that an enemy will be able to destroy several transmission facilities and/or jam several transmission links. However, the distributed network structure postulated can operate effectively in a high attrition environment, as described above. The links are assumed to be encrypted, which would reduce the amount of information acquired by an enemy who intercepts a transmission and make spoofing difficult. An enemy who locates a ground-to-air transmitter will not learn the activity level at nearby C^2 facilities if the radios used for communications with mission aircraft are a resource available to all users of the switched network.

Implementing the concepts governing the postulated future architecture should not increase the transport requirements of the various TACS elements. The set-up times for the switching and technical control equipment should be reduced, because the new switches will be smaller and more intelligent, but the set-up times and power requirements for the transmission equipments should not be affected.

SECTION 7

REQUIRED ACTIVITIES

An alternative set of concepts governing a future TACS communications architecture were described in section 6. Before these concepts can be implemented, several investigations and development activities must be performed. These efforts should apply the technology expected to be available in the 1990's to the TACS-unique requirements.

The required activities have been segregated into three related categories: 1) network feasibility analysis; 2) network protocol development; and 3) analysis of alternative configurations for communications with mission aircraft. The activities in each category are listed below.

7.1 NETWORK FEASIBILITY ANALYSIS

The following analyses should be performed to determine if a highly distributed, packet-switched network to support the future TACS is actually feasible:

1. Verify that the propagation delays expected to occur in the highly distributed network can be kept small enough to ensure that information will be delivered while it is valuable. Switch processing speeds and capacity should be based on reasonable assumptions of technology available in the 1990's.

2. Determine how interfaces between elements of the packet switched network and other TACS equipments can be implemented.

3. Estimate the relative cost of developing and demonstrating the packet switching hardware and software. The estimates should be relative to the cost of obtaining similar equipment for a TACS using today's communications concepts. The designs should proceed from reasonable assumptions of 1990's technology.

7.2 NETWORK PROTOCOL DEVELOPMENT

Protocols and procedures should be developed for the packet-switched network that accomplish the following functions:

1. Distributes diverse types of information efficiently to a single destination, to a small group of destinations, or to all possible destinations. The network should determine when it is preferable to send a packet to all switches rather than a group of switches.

2. Delivers time-sensitive information while it is valuable.

3. Allows one or more message subsets to receive processing and transmission priority.

4. Allows the use of link and end-to-end packet acknowledgements.

5. Transmits voice packets only when a speaker is actually talking.

6. Governs voice conference calls efficiently via a distributed control algorithm.

7. Allows an authorized network subscriber to access an unassigned radio, either on the ground or in an airborne relay, for communications with mission aircraft.

8. Delivers a message transmitted by an aircraft, received by a radio on the ground or in an airborne relay, and intended for a ground-based network subscriber.

9. Distributes network and subscriber connectivity information for planning and technical control purposes. If feasible, link delay information should be exchanged to allow packets to be routed along paths experiencing the least delay.

10. Adapts packet sizes to changes in network status in order to optimize transmission efficiency.

11. Identifies identical voice packets to minimize network loading.

12. Supports the Immediate Air Request network if MILSTAR is not available.

7.3 ANALYSIS OF ALTERNATIVE CONFIGURATIONS

The following configurations for communications with mission aircraft should be refined and compared. The term "radio" below refers strictly to those transmission systems (JTIDS, EJS or HAVE QUICK, SINCGARS, UHF, and VHF) that support communications between ground-based users and mission aircraft. These radios may be on the ground or located in airborne relays, depending on the configuration chosen.

1. A purely ground-based configuration in which any authorized subscriber of the packet switched network can access any ground-to-air radio.

2. A hybrid combination of ground-based and airborne radios in which a single ground-based packet switched network interface is provided for each operating airborne relay. An authorized subscriber can access any ground-based or airborne radio. The airborne radios are accessed through the interface station dedicated to the airborne relay.

3. A hybrid combination of ground-based and airborne radios in which an airborne relay can communicate with several packet switched network interface stations that are located at each operations module. An authorized subscriber can access any ground-based radio and all airborne radios on relays within line-of-sight of the subscriber's interface station.

The three configurations should be compared with respect to:

a. simplicity
b. concealment of Order of Battle
c. jamming resistance
d. survivability
e. system set-up time
f. cost

Anti-Jam data links presently in development should be assessed as alternatives for configuration #3, as defined above.

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APPENDIX A

BASELINE COMMUNICATIONS EQUIPMENT

The equipments identified and described in this appendix will form the hardware baseline, if no further development activities are initiated, for developing a communications network to support TAC's time-critical command and control activities in the year 2000. These equipments include items in the present TAC inventory and those new or modified systems that are expected to be operational within the next ten years.

Equipments in five different categories are described below. The first category, wide area transmission equipment, is considered in section A.1. Local area transmission equipments are similarly identified in section A.2. Transmission equipments used for communications with mission aircraft are characterized in section A.3. Switching equipments are detailed in section A.4. Technical control equipment is particularized in section A.5.

A.1 WIDE AREA TRANSMISSION EQUIPMENT

AN/TRC-170( ) (V) Radio Terminal Set. A family of transportable digital troposcatter radio assemblages that provide transmission for up to 64 channels at rates up to 2048 kbps for ranges up to 200 miles. The equipment includes a bulk link encryption capability. Present procurement plans are for the (V)2 configuration, which includes dual 9.5 foot diameter antennas and a nominal 150 mile transmission path. Each AN/TRC-170 includes two TD-1235 Loop Group Multiplexers, four MD-1026 Group Modems and one TD-1236 Trunk Group Multiplex. This equipment will accommodate up to 30 4-kHz analog or 32 kbps digital loop subscribers and up to four digital group interfaces. The equipment is also compatible with various cable modems and orderwire units.

AN/TSC-60 Communications Central. This is an HF, AM or SSB, radio system for long-haul communications. It includes two transmitters and two receivers, each capable of full-duplex operation. Each radio can provide four channels. This radio set can accommodate up to eight telephone subscriber lines, either 2-wire or 4-wire. It supports voice, teletype, and data traffic between TACS elements. The AN/TSC-60 V (1) has 1 kw power amplifiers, the V (2) has 2.5 kw power amplifiers. The V (3) consists of a V (2) central plus a single 10 kw power amplifier.

AN/TSC-94A Non-nodal Terminal. This is a single-channel, transportable, ground terminal for SHF satellite system communications. It provides transmission capacity for one TRI-TAC 15-channel group access plus up to 23 local subscriber accesses via two low-rate multiplexers. Subscribers may be either analog or digital. It is compatible with the AN/TSC-100A terminal.

AN/TSC-100A Nodal Mesh Terminal. This is a transportable ground terminal for SHF satellite communications that can operate with two satellites and up to four terminals. It is compatible with the AN/TSC-94A. Each link provides up to sixty full-duplex voice frequency lines by means of TD-660 PCM voice multiplexers and associated equipment, and one 16/32 kbps TRI-TAC digital circuit interface.

MILSTAR Satellite System. The Military Stategic-Tactical and Relay (MILSTAR) satellite program is acquiring both satellites and terminals to support jam resistant satellite communications links for both strategic and tactical users. The satellite portion of the system will include at least seven orbitting satellites providing world-wide coverage including the polar regions. The satellites will provide switching capabilities and will include integral control systems to eliminate the need for ground control stations. The satellites will have the capability to provide communications to ground, airborne, and surface terminals and will, by means of frequency hopping and error correction coding, be able to provide secure, jam resistant voice and data communications for a limited number of users. These capabilities will be achieved with a 44 GHz frequency division multiple access uplink, a 20 GHz time division multiple access downlink, and a 60 GHz satellite crosslink. The ground portion of the system will include small, highly transportable terminals such as the Single Channel Objective Tactical Terminal (SCOTT) and others to provide a wide variety of satellite terminal installations. In addition to the 20 GHz downlinks, there will also be a limited UHF capability to ensure compatibility with current UHF users.

Short Range Wideband Radio. Short Range Wideband Radio (SRWBR) is an overall conceptual name for a number of line-of-sight microwave radios. These radios use the frequency ranges from 4 to 60 GHz. This range includes portions of both the microwave and millimeter wave bands. No specific Air Force equipment is currently being procured. In general, SRWBR can accommodate data rates of up to 18 Mbps and path lengths of up to 24 kilometers. The SRWBR would require the use of separate digital group multiplex and could be packaged for hand-carried applications, shelter configurations, or for small-vehicle transport. The vehicle and shelter installations could also make use of trailer mounted antenna masts to provide higher antenna elevations and additional path clearance and greater link distances. Erection time is expected to be approximately thirty minutes with a maximum crew size of two. The supporting multiplex equipment would be consistent with TRI-TAC standards.

A.2 LOCAL AREA TRANSMISSION EQUIPMENT

CX-4566A/G Cable Assembly. A 250-foot, 26-pair cable, terminated at each end with a hermaphroditic connector. The cable is intended for local site shelter-to-shelter connections for landlines. Cables may be connected in tandem to approximately two miles.

CX-11230 Coaxial Cable. Provides high capacity transmission between TRI-TAC equipments.

MD-1026 ( ) (P)/G Group Modem. The Group Modem (GM) is used to interface the LGM and TGM group outputs with CX-11230 coaxial cable. The group modems are used in conjunction with the LGM, RLGM, TGM, and MGM units described below and are packaged in a case containing up to 6 group modems.

TD-206. PCM Cable System for the TD-660 Multiplexer. Used with GMF satellite terminals.

TD-1233 Remote Loop Group Multiplexer (RLGM). Accepts four 32 kbps channels for transmission to an MGM or TGM via a cable driver or an RMC. One half-rate channel is used for overhead which includes framing and telemetry for a maximum output of 144 kbps.

TD-1234 Remote Multiplexer Combiner (RMC) Accepts eight 32 kbps channels or extends remote multiplexing capability by accepting RLGM outputs at 144 kbps or other RMC output of 288 kbps for transmission to an MGM or LGM via a group modem (GM).

TD-1235 Loop Group Multiplex (LGM). Accepts up to sixteen 32 kbps subscriber circuit inputs and forms them into a single group at 512 kbps. Part of AN/TRC-170.

TD-1236 Trunk Group Multiplex (TGM). Accepts four 512 kbps groups and forms them into a super group at 2048 kbps.

TD-1237 Master Group Multiplex (MGM). Accepts up to twelve 2,048 kbps super groups and forms a master group.

Fiber Optics. Fiber optic equipment may be used to provide remote operation capabilities for communication radios or for radars, to reduce weight and bulk of connecting cables, and to provide very high bandwidth links between and within individual command and control facilities. There are a number of current programs with general communications applicability:

Tactical Generic Cable Replacement (TGCR). This is an advanced development program, directed by RADC jointly with Army CECOM, to develop a processor-controlled, universal replacement for CX-4566 cable, needing no adjustment in operation with any interface over distances between 0.3 and 6.3 kilometers. Production TGCRs will be the first system in a proposed family of standard fiber optic transceivers. TGCR will be used to remote radios and interface shelters at the TACC, CRC/P, FACP, and ASOC.

Fiber Optic Transmission System - Long Haul (FOTS-LH). This is an Army replacement for CX-11230.

A.3 TRANSMISSION EQUIPMENT FOR COMMUNICATIONS WITH MISSION AIRCRAFT

AN/GRC-206 Radio Set. A vehicle-mounted radio equipment package. It will replace the AN/MRC-107/108 radio set. It has transmit and receive capabilities in the following frequency ranges: a) HF, b) VHF/FM, c) VHF/AM, and d) UHF. May be mounted in either the M-151, 1/4-ton utility vehicle or the M-113A1 armored personnel carrier.

AN/TRC-87. This is a UHF radio communications set that provides five AM simplex voice channels. Four transmitter/receiver groups provide fixed frequency operation, one group provides remote frequency selection. The nominal output power is 100 watts.

AN/URQ-28 (V). The JTIDS Class 2 Terminal. JTIDS provides secure data and voice communications over normal ranges of up to 300 nautical miles and up to 500 nautical miles with extended range operation. Built-in automatic relay capabilities will provide additional range or relays for terminals not within line of sight of each other. The system operates in the 960 to 1215 MHz and uses frequency hopping, error detection and correction coding, and interleaving techniques to provide antijam protection. The system also has built-in identification, relative position location capability based on time-of-arrival techniques, and digitized voice capabilities. The JTIDS provides for a maximum of 128 different networks with approximately 30 networks operating in one geographic area.

The Class 2 Terminal is designed for use in fighter aircraft. It is anticipated that the Class 2 terminal will replace the Class 1 units prior to the time frame of this study (see AN/URQ-33).

AN/URQ-33. The JTIDS Class 1 Terminal. The Class 1 terminal is designed for use in the E-3A and in ground facilities.

Enhanced JTIDS. The Enhanced JTIDS System (EJS) is a jam-resistant voice communications radio for air-to-air and air-to-ground use. During peacetime, the EJS will operate in the traditional military UHF frequency band. During combat operations, the transmissions will be shifted to a higher frequency band. The system incorporates frequency hopping techniques to provide a secure sixteen kilobit per second continuously variable slope delta modulated voice communications capability. Five terminal types are planned to support various platforms and network capabilities. The Tactical Airborne Set will be installed in fighter aircraft and will receive one signal on a wide-area net and two signals on a local-area net. Airborne Command and Control Sets, which will be installed in E-3A aircraft, will support both wide-area and local nets with as many as eight independent operator stations. Vehicles, such as jeeps, will be provided with Ground Command and Control Mobile Sets with single channel capability. The Ground Command and Control Transportable Set would be used for up to four operator stations on local- or wide-area nets and up to twelve, independent, collocated radios. A Manpack Radio Set is also planned. Short-range remote control options are currently being investigated.

SINCGARS-V. The Single Channel Ground-Air Radio System (SINCGARS) V program is developing a VHF, spread-spectrum, mobile radio to be used, primarily by the Army, to replace the existing radios for mobile and portable, VHF-FM, Combat Net Radio Applications. The Air Force will also use this equipment to support joint operations such as close air support missions. The equipment will function at a transmitter output power of either 10 or 50 watts and can be operated from a remote-control unit placed up to 4 km away from the radio. Cryptographic equipment can be placed at either location. Multiple radio opertion at a single site is possible.

HAVE QUICK. HAVE QUICK is a secure voice UHF-AM radio system. It was designed as an interim means to provide secure voice capability until Enhanced JTIDS is available. It uses slow frequency hopping for spectrum spreading and operates in the 225 to 400 MHz UHF band. HAVE QUICK radios are modified versions of AN/ARC-164 or AN/GRC-171 radios. They operate in a manner similar to single channel UHF radios, with the user selecting a net (hopping pattern) rather than a single frequency. They also include a separate receiver module to provide a fixed frequency guard channel for emergency situations. Collocated radios must use a smaller portion of the spectrum, reducing jam resistance. Future versions of HAVE QUICK will allow all collocated radios to hop over the entire 225 to 400 MHz range. In the hopping mode (active mode), HAVE QUICK allows conferencing. If an operator attempts to transmit while another transmission is occurring, the radio will shift down 25 kHz. Since receivers have a 70 kHz wide bandwidth, both signals can be received.

A.4 SWITCHING EQUIPMENT

AN/TTC-39 Automatic Telephone Central Office. A TRI-TAC developed, electronic, hybrid (analog and digital) circuit switch with either 300 or 600 line capacity to automatically interconnect subscribers and interswitch trunks. It has conference, precedence, multiplexing and security capabilities, and automatically responds to instructions from the AN/TSQ-111 Communications Nodal Control Element.

AN/TTC-42 Automatic Telephone Central Office. A digital 150-line TRI-TAC tactical circuit switch of the Unit Level Switch Program. Can accommodate up to 24 analog trunks and loops. The switch includes security and multiplex equipment and is housed in a single S-280 shelter.

SB-3865( ) (P)/TTC Automatic Telephone Switchboard. A 30-line, automatic, digital circuit switch of the Unit Level Switch Program. Provides service to secure and non-secure subscribers and selected four-wire analog loops and trunks. May be combined with up to two additional units to provide 60 or 90-line capacity. Contains three time division multiplexed trunk groups, each having 18-channel capacity, for interface via coaxial cable to other SB-3865s, AN/TTC-42s, AN/TTC-39s, and to SHF Satellite Terminals.

AN/TYC-11 Automatic Message Switching Central. A tactical automatic, 12-line, rack-mounted message switch configured for inclusion in TRI-TAC mobile communications shelters. Provides a store-and-forward service and unit level message switch network access.

AN/TYC-39 Automatic Message Switching Central. A store and forward message switch for up to 50 tactical subscribers. It also provides AUTODIN access into the Defense Communications System. It can operate either with or independent of a AN/TTC-39 circuit switch. It provides status data and responds to Communications Nodal Control Element (CNCE) directives. Overall capabilities include security, message accountability, verification or character/bit integrity of all message traffic, 30-day journal storage, six levels of precedence, and continuous traffic monitoring.

A.5 TECHNICAL CONTROL EQUIPMENT

AN/TSQ-111 Communications Nodal Control Element. Provides the means to assign communications and COMSEC resources at a communications node. It provides interconnects and interfaces for analog and digital equipment, circuit switches, and store-and-forward switches. Type I is a dual shelter configuration. Type III is a single shelter configuration. Only the Type III configuration is being procured at this time. The type III configuration is equipped for a maximum of 72 analog channels, 256 digital channels at 32 kbps, and 25 digital groups of 15 channels each. It includes a master timing clock for TRI-TAC equipment synchronization.

APPENDIX B

SWITCHING TECHNOLOGIES

Two basic approaches are used to distribute information among users in a network. Dedicated circuits can be provided between pairs of subscribers to allow minimal-delay communications. However, if the number of subscribers is large, as in the TACS, the number of dedicated circuits required will be very large. A switched network reduces the number of circuits required by linking each user to a switch and then interconnecting the switches. There are three switching technologies currently in use: circuit, message, and packet switching. The relative merits of each of these switching technologies, as well as hybrid combinations of them, are discussed in the following paragraphs.

B.1 CIRCUIT SWITCHING

A circuit switching network establishes an end-to-end circuit between two subscribers for each call. The circuit consists of a fixed amount of network resources, in time and bandwidth, dedicated to a single call for its duration. The circuit emulates a direct full-duplex, four-wire line between the users, providing a high degree of network transparency. The full-duplex circuit is inefficient unless both subscribers are transmitting simultaneously for the duration of the call, which is an atypical application.

A circuit switch must be aware of the complete network structure and connectivity to establish an end-to-end circuit for an incoming call. If network resources are not available, the call is blocked and dropped from the network. Sufficient network capacity must be provided to keep the blocking probability to an acceptable level.

Information can be transmitted without overhead after an initial call setup procedure is successfully completed. Therefore, circuit-switching efficiency is maximized when the information transmission time is much longer than the call setup time. Circuit switching networks have been deployed worldwide primarily to support relatively long voice communications. Short-length data messages can be handled in one of two ways. A traditional approach is to establish a call for an entire interactive data session, and the circuit is left idle when information is not being transmitted. Alternatively, a circuit can be established and disconnected for each short-length message. However, even moderate amounts of data traffic applied to a primarily voice circuit-switched network will greatly increase network switching requirements. Therefore, circuit switching is not efficient for an integrated voice and data network.

B.2 MESSAGE SWITCHING

Message switching systems do not provide an end-to-end circuit between an information source and destination. Instead, messages are relayed on a store-and-forward basis. After delivery to an originating switch, a message is sent through the network, being stored in its entirity at each relay point. Messages are not discarded when sufficient network resources are unavailable at a given switch. Each message is placed in a queue until capacity becomes available and delivery to the intended destination(s) is possible.

The fact that messages queue up at each switch allows the network transmission resources to be used extremely efficiently. However, the efficiency is achieved at the expense of long average message delay and message delay variance statistics. For example, a message placed in a queue behind a long message will experience a correspondingly longer delay. Message switching is therefore often used to relay information that is not affected adversely by long end-to-end transmission delays.

Several other message switching characteristics become evident by considering the fact that messages are stored in their entirety at the various switches. Large storage devices are obviously required at each switch. The ability to store complete messages long after they have been delivered may be required in some applications.

A more subtle message switching advantage results from the fact that the end-to-end communications paths established do not emulate direct two- or four-wire circuits. This allows the switches to perform protocol and code conversions, which permit various types of terminals to communicate.

B.3 PACKET SWITCHING

Packet switching is a special type of message switching that maintains message switching's advantages but resolves the long average message delay and delay variance problems. Favorable delay statistics are achieved by not allowing long messages to interfere with short messages. The length of any single transmission is limited to a predetermined maximum, typically less than a few thousand bits. Messages exceeding the maximum length are partitioned into packets.

As in message switching, the packets are relayed on a store-and-forward basis. However, less storage capacity is required at each switch because the switches only have to store packets rather than complete, possibly lengthy messages. Packets can be discarded after they are forwarded successfully.

There are two principal approaches used to govern the routing of information in a packet switching network. One approach, known as datagram service, routes the individual packets in a multiple-packet message independently. Each packet must therefore contain identification and routing information. Packets can be routed dynamicall around disabled stations or links experiencing long transmission delays. However, because each packet is routed independently, the propagation delay may vary from packet to packet. Packets may even arrive out of sequence, be lost, or duplicate packets may be received. Although these anomalies are acceptable for short-length data communications, a constant propagation delay is preferable for voice communications. Since each packet contains overhead routing information, datagram service is inefficient for long multiple-packet messages, such as voice.

The packet virtual circuit (PVC) approach establishes a fixed end-to-end circuit through the network for each message. After the path is established, each packet in the message is relayed along the virtual circuit. Since voice information can tolerate a higher bit-error rate than data communications, voice packets do not require error detection or individual acknowledgments. The voice packets traversing the virtual circuit will therefore experience a nearly constant propagation delay.

The PVC technique is similar to circuit switching in that a call setup procedure must be followed, but minimal other overhead is necessary. The PVC algorithm is therefore efficient for long multiple-packet messages.

B.4 HYBRID SWITCHING

An information distribution system can use a mix of circuit, message, and packet switched circuits as well as dedicated circuits. The baseline TACS communications network uses a mix of dedicated circuits, circuit switching, and message switching. A hybrid switching technique is most advantageous, although not necessarily the most cost-effective solution, when messages with diverse distribution requirements must be exchanged. For example, circuit switching could be used to route voice and long data messages, and packet switching could be used to route short-length data messages.

APPENDIX C

AIRBORNE RELAY COMMUNICATIONS

This appendix provides supplemental information concerning alternative means of using an airborne relay for communications between static facilities and mission aircraft.

C.1 ALTERNATIVE CONFIGURATIONS

Two alternative airborne relay configurations have been examined in some detail. A third configuration, in which a relay is dedicated to each operations module, was considered originally. This alternative was dismissed because its dependence on the use of tethered lighter-than-air devices makes it impractical in a tactical situation.

Each configuration includes airborne relays and ground-based facilities, which serve as the interface between the airborne relays and C^2 facilities. An interface station may be a subsystem integral to a C^2 center or it may be a separate facility. The interface stations provide the switching, multiplexing, antenna control, spectrum spreading, and any other capabilities needed for a particular relay configuration.

C.1.1 Ground Station/Platform Pairing (GSPP)

Each airborne relay is paired with a dedicated, ground-based interface station in the Ground Station/Platform Pairing (GSPP) configuration. The packet-switched network relays information between the interface stations and the C^2 facilities. A subscriber needing the use of a radio on an airborne relay sends a radio request message to the appropriate interface station. If a suitable radio is available, it is allocated to the requesting subscriber and retuned to the subscriber's assigned channel. Communications between an airborne relay and its interface station will take place using a multiplexed, digital data link. Transmissions between several ground-based subscribers and mission aircraft share each multiplexed link. Redundant interface stations are used to provide back-up communications in the event one or more of the interface stations are destroyed.

C.1.2 Ground Station/Operations Module Pairing (GSOMP)

Multiple interface stations can access the same airborne relay in the Ground Station/Operations Module Pairing (GSOMP) configuration. There are more interface stations in this configuration and each station serves fewer subscribers, such as those in a single operations module. An interface station might be installed in an operations module or might be in a separate module.

When a subscriber in an operations module needs a radio on an airborne relay, he accesses the nearby interface station. The interface station then transmits a radio request message to the appropriate airborne relay. The request may be transmitted when it is received, or it may wait until the airborne relay asks for new radio requests. If a suitable radio is available, the airborne relay makes the assignment.

The GSOMP configuration is similar to the Low Cost, Anti-Jam Data Link (LCAJDL) being developed for RADC. Both support communications between an airborne relay and multiple ground stations. However, a remote terminal must be installed in the mission aircraft to use the LCAJDL equipment. For this study, it has been assumed that no changes can be made to mission aircraft. The LCADJL master terminal in an airborne relay polls the ground stations to find users in need of a radio. A polling technique is required for the LCAJDL system because the antenna on the airborne relay is sequentially pointed toward each ground station.

C.1.3 Comparison of Alternative Configurations

The chief difference between the two airborne relay configurations is in the number of interface stations and the means by which they are accessed. The GSPP alternative requires relatively fewer interface stations and, consequently, fewer interface-station-to-airborne-relay links. The GSPP configuration also provides a more flexible system when the switched network is functioning effectively, since a subscriber can access any available radio. However, because fewer interface stations are used, it is easier to disrupt communications by destroying an interface station. An interface station in the GSPP configuration is a valuable target because it performs the radio assignment function for all the radios in its associated airborne relay. It is also possible to disrupt airborne relay communications in the GSPP configuration by disabling the switched network sufficiently to impair information flow between subscribers and interface stations.

The GSOMP configuration can support airborne relay communications even when significant portions of the switched network have been destroyed, since each operations module has an associated interface station. For the same reason, airborne relay communications in this configuration will not use significant amounts of the switched network capacity.

A variation of the GSOMP alternative uses the switched network to provide supplemental back-up links for communications between operations modules and interface stations. In situations of high attrition, the surviving portions of the switched network could be used to pair the remaining operations modules and interface stations.

One disadvantage of pairing the operations modules and the interface stations is that the latter's RF emissions (directed toward airborne relays) may reveal the location of the C^2 facilities. The GSPP configuration avoids the location problem because an interface station paired with an airborne relay can be at any location in the switched network.

The airborne relays in the GSOMP configuration are relatively more complex because they perform the radio assignment function and communicate with numerous interface stations. Although somewhat less complex than in the GSPP configuration, the interface stations in the GSOMP configuration will still be rather complex and will be required in greater numbers.

C.2 AIRBORNE RELAY LOCATION

The location of each airborne relay should be chosen to balance the conflicting requirements of maximum coverage and minimum susceptibility to jamming. The relay will ideally be high enough to provide line-of-sight coverage throughout the theater, but remain below the line of sight of potential ground-based jammers and surface-to-air missiles.

Locating an airborne relay near the Forward Edge of the Battle Area (FEBA) would increase the strength of radio signals received by mission aircraft. However, because the relays must maintain an altitude sufficient to ensure line of sight with rear-area interface stations, the forward-area relays will most likely be within line of sight of ground-based jammers and munitions.

More rearward locations for the airborne relays would be less vulnerable. A link between a relay and a ground-based interface station would be more difficult to jam, but the link between the relay and the mission aircraft would be correspondingly easier to jam. A location in the middle of the theater appears to be optimum.

C.3 NUMBER OF AIRBORNE RELAYS

Based on the terminals presently envisioned, cosite interference considerations limit the number of EJS channels that can be used in a single location to eight. This limit was used to estimate the number of airborne relays needed to support communications with mission aircraft for a TACS. If the limit changes, or if EJS is not used, the required number of airborne relays would also change. The determining factor is the number of radio channels that can be collocated in an airborne relay.

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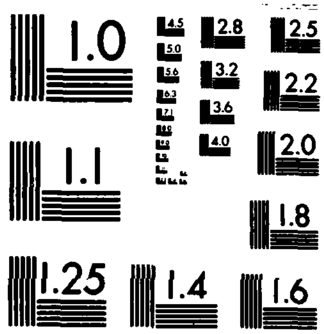

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

It was assumed that a ground-deployable TACS includes 20 operations modules. Each module is assumed to contain four consoles, of which half might be used by personnel needing to communicate with mission aircraft. If the present concept of assigning a single channel to each subscriber is maintained, a total of 40 channels would therefore be required. Since it has been assumed that only eight channels can be provided by a single relay, a total of five relays is required to provide the 40 channels. Of course, to keep five relays airborne continuously, many more (approximately 20) must be furnished.

C.4 ANTENNA SYSTEM CONSIDERATIONS

Each airborne relay will be linked to one or more interface stations on the ground. Antenna design trade-offs at both ends of these links must be considered. The airborne relays and the interface stations are paired in the GSPP configuration. Therefore, narrow beamwidth tracking antennas can be used at each end of these links to improve performance.

The interface stations need to communicate with multiple airborne relays in the GSOMP configuration. If a tracking antenna is used at an interface station, the station will only be able to access one airborne relay at a time. In other words, all radio channels being accessed by an interface station would have to be on the same airborne relay. If a wide beamwidth antenna is used at an interface station, the station could access multiple airborne relays simultaneously. However, links using wide beamwidth antennas are easier to detect and to jam.

A wide beamwidth antenna on an airborne relay would allow the relay to listen for a transmission from any one of a group of interface stations on the ground. This capability would permit interface stations to submit radio channel requests to an airborne relay during designated time periods. If, however, a narrow beamwidth tracking antenna is used on the airborne relay (as in the LCAJDL scheme), the relay would have to either sequentially poll the interface stations or use a pre-arranged, time-division-multiple-access technique to receive radio requests.

A two-step procedure could be used to facilitate the aiming of tracking antennas. A moderate beamwidth antenna pattern could be used for establishing contact, and a narrower beamwidth could be used after the link was established. Position information, such as that provided by JTIDS, could be used to steer the antenna.

C.5 MULTIPLE RELAY

The link between an interface station on the ground and mission aircraft can be configured with one or more airborne relays. The number of relays required depends on the location of the interface station, the location of the aircraft, and the expected jamming environment.

One reason for using multiple relays is to increase the communications coverage range. However, in a tactical environment, one relay can typically cover the entire deployment region. A more appropriate reason for using multiple relays in the TACS is to improve the performance under jamming. The second relay would have to be closer to the FEBA to realize this improvement. Due to its proximity to hostile territory, this relay would be vulnerable to SAMs. In addition, multiple relays increase the number of aircraft required, and the additional links require a portion of the scarce frequency spectrum.

C.6 COMMUNICATIONS BETWEEN AIRBORNE RELAYS

In addition to the multiple relay configuration discussed above, there is one other situation in which the capability to send information between airborne relays would be beneficial. In the GSPP configuration, the switched network is used to link a subscriber in an operations module with an interface station selected by the subscriber (or, more likely, the subscriber's computer). If a portion of the switched network is disabled, it might not be possible to establish the desired link. However, a link between the subscriber and another interface station might be realizable. Thus, a link between the desired airborne relay and the relay paired with the accessible interface station would be useful.

C.7 LOW COST ANTI-JAM DATA LINK

This section is a brief, functional description of the LCAJDL being developed by Hughes Aircraft under contract to RADC. More detailed information is available in the "Low Cost Anti-Jam Data Link Study," Hugh 2092.

The LCAJDL is designed for communications and position location in a TACS, as well as for weapons control. Net management for the system resides in the Airborne Master Control Station (AMCS), located in an airborne relay platform. A Ground Control Station (GCS) tracks the AMCS and provides it with position and command data. The AMCS searches for new network members and polls existing ones for service requests using a tracking antenna system.

Ground-Based Remote Terminals (GBR) located in jeeps can be linked with other GBRs, with Airborne Remote Terminals (ART) in mission aircraft, or with Weapon Remote Terminals (WRT) in munitions. The network will support at least 20 full-duplex channels.

The LCAJDL uses carrier frequencies in the 15 GHz band using separate frequencies for the uplink and the downlink. It uses pseudo-noise (20 MHz chip rate), spread-spectrum modulation and allows for expansion to a frequency-hopped system.

The LCAJDL represents a particular version of the GSOMP configuration presented in this study, in that every ground facility can be collocated with an airborne relay interface station (in this case, the GBR terminal). Some important choices, which have been left open in this study, have been made for the LCAJDL. In particular, a carrier band has been chosen (SHF) and a polling system with separate uplink and downlink frequencies has been specified. The LCAJDL system assumes tracking antennas, which is an option in our study.

One very important difference is that the LCAJDL requires modification to mission aircraft in the form of a pod-mounted ART. This was not allowed for the purposes of the Assured Information Flow Capping Architecture Study. The results of the LCAJDL study are certainly applicable to the Future TACS, but system modifications would be necessary.

LIST OF ACRONYMS

AFAC	Airborne Forward Air Controller
ALCE	Air Lift Control Element
AMCS	Airborne Master Control Station
ARIS	Airborne Relay Interface Station
ARP	Airborne Relay Platform
ARPA	(Defense) Advanced Research Projects Agency
ART	Airborne Remote Terminal
ASGS	Air Surveillance Ground Station
ASOC	Air Support Operations Center
AUTODIN	Automatic Digital Network
bps	Bits per Second
C^2	Command and Control
CCT	Combat Control Team
CECOM	Communications and Electronics Material Readiness Command
CNCE	Communications Nodal Control Element
CRC	Control and Reporting Center
CRP	Control and Reporting Post
CS	Circuit Switch
CTC	Combat Theater Communications
DSCS	Defense Satellite Communications System
EJS	Enhanced JTIDS System
ESD	Electronic Systems Division
FACP	Forward Air Control Post
FEBA	Forward Edge of Battle Area
FOTS-LH	Fiber Optic Transmission System - Long Haul
G/A	Ground/Air
GACC	Ground Attack Control Center
GBR	Ground-Based Remote Terminal
GCS	Ground Control Station
GM	Group Modem
GMF	Ground Mobile Forces
GSOMP	Ground Station/Operations Module Pairing
GSPP	Ground Station/Platform Pairing
HF/SSB	High Frequency/Single-Side Band
IARN	Immediate Air Request Network
IM	Intelligence Module
JTIDS	Joint Tactical Information Distribution System
kbps	Kilobits per Second
LAN	Local Area Network
LCAJDL	Low Cost, Anti-Jam Data Link
LGM	Loop Group Multiplex
Mbps	Megabits per Second
MCE	Modular Control Equipment
MGM	Master Group Multiplex
MILSATCOM	Military Satellite Communications System
MILSTAR	Military Strategic-Tactical and Relay

LIST OF ACRONYMS
(CONCLUDED)

OM	Operations Module
PLSS	Precision Location Strike System
PVC	Packet Virtual Circuit
RADC	Rome Air Development Center
RALP	Recognized Air/Land Picture
RLGM	Remote Loop Group Multiplexer
RMC	Remote Mutiplexer Combiner
SAM	Surface-to-Air Missile
SCOTT	Single Channel Objective Tactical Terminal
SF	Support Facility
SHF	Super High Frequency
SINCGARS	Single Channel Ground Air Radio System
SRWBR	Short Range Wide Band Radio
SW	Switch
TAC	Tactical Air Command
TACC	Tactical Air Control Center
TACP	Tactical Air Control Party
TACS	Tactical Air Control System
TAF	Tactical Air Force
TAFIIS	Tactical Air Forces Integrated Information System
TC	Technical Control
TDM	Time Division Multiplexed
TDMA	Time Division Multiple Access
TGCR	Tactical Generic Cable Replacement
TGM	Trunk Group Multiplex
TIE	Tactical Information Exchange
TRI-TAC	Tri-Service Tactical Digital Communications System
UHF	Ultra High Frequency
VHF	Very High Frequency
WOC	Wing Operations Center
WRT	Weapon Remote Terminal

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